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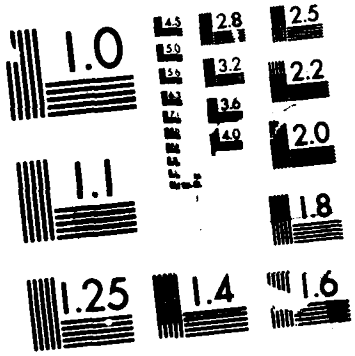

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TECHNICAL REPORT BRL-TR-2839

120-mm REGENERATIVE LIQUID PROPELLANT GUN: A PARAMETRIC INVESTIGATION OF THE INTERIOR BALLISTICS

GLORIA P. WREN

AUGUST 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A sensitivity study of a 120-mm regenerative liquid propellant gun was completed to explore the relationships between the variables as expressed in the interior ballistic code developed by T. Coffee at the Ballistic Research Laboratory. Parametric runs were conducted by varying an array of input parameters by +-10% and +-20%, and the effects on performance characteristics were recorded. In the second phase of the study a constraint of maximum liquid pressure equal to 700 MPa was imposed to determine the effect of a parameter change while maintaining gun performance. This report summarizes the major results and examines the interrelationships exhibited.

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I. INTRODUCTION

The regenerative liquid propellant gun continues to be of interest to gun designers both for its potential for increased performance and the lower vulnerability of liquid propellants compared to solids. Recent research has indicated increased understanding of the RLP process, and several interior ballistic models are now available. Although mathematical models have been created for the U.S. gun configurations (Bulman,[1] Coffee,[2] Cushman,[3] Gough[4]), the interrelationships between the complex variables associated with the liquid propellant gun continue to be elusive. Thus, this sensitivity study is aimed at exploring the relationships expressed in the mathematical modeling of a hypothetical 120-mm regenerative liquid propellant gun, using the model developed by T. Coffee[5] at the Ballistic Research Laboratory. The information gained from this study may also aid in the design of regenerative liquid propellant guns other than the 120-mm studied here.

The Coffee code is a lumped parameter model of a regenerative liquid propellant gun, using an annular piston injector as shown in Figure 1.

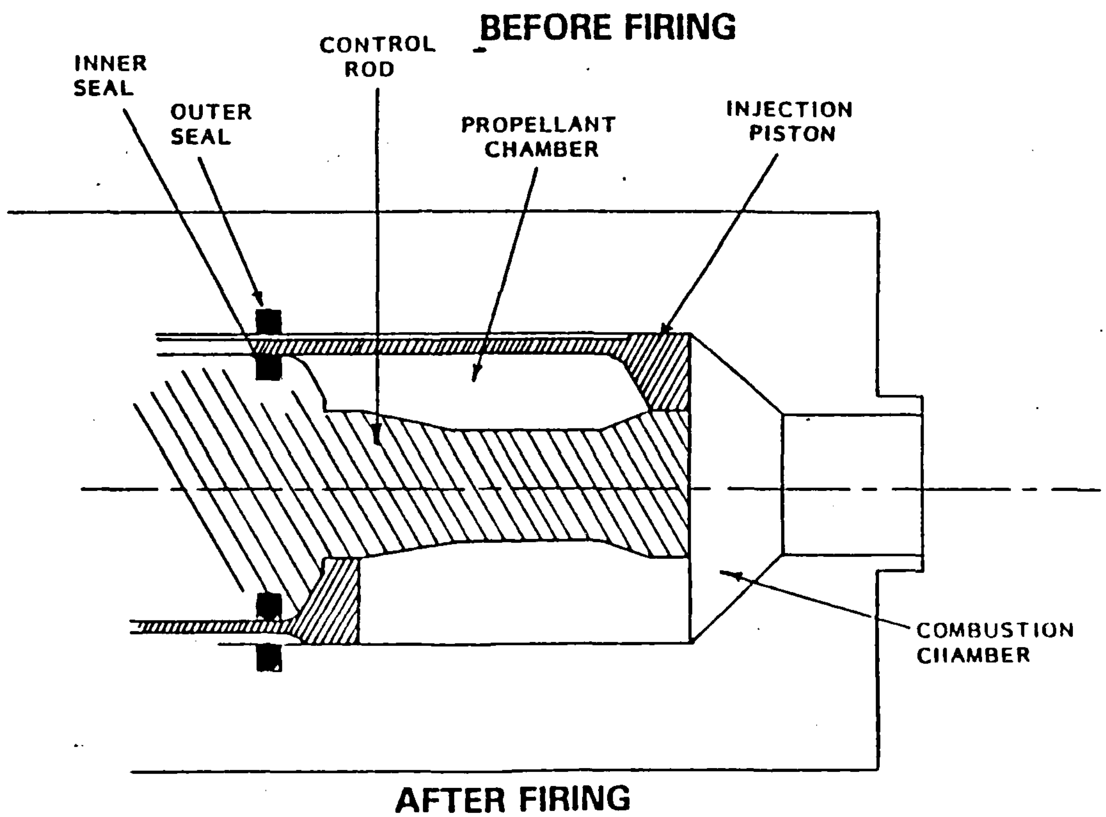

Figure 1. RLP Gun With Annular Piston

The interior ballistic cycle starts with a primer igniting in the combustion chamber pressurizing the chamber, forcing the piston back. The liquid pressure is higher than the combustion chamber pressure due to the piston area differential between the two regions. Liquid propellant is forced through the vent created between the piston and the fixed center bolt into the combustion chamber where it burns, and the resulting pressure pushes the projectile down the gun tube. In this report the piston area on the combustion chamber side is referred to as the chamber area while the piston area on the liquid side is referred to as the liquid area.

II. SENSITIVITY STUDY

1. STANDARD DATA SET

The standard data set for this study was chosen to be the conceptual 120-mm regenerative liquid propellant tank gun with no offset (that is, the base of the projectile is at the entrance to the bore) using a hypothetical JA2 propellant and a projectile mass of 7.12 kg as presented in Table 1.

TABLE 1. 120-mm RLP Gun Standard Case Input Data

VARIABLE	VALUE
Projectile Weight (kg)	7.12
Projectile Travel (m)	6.3
Piston Weight (kg)	76.66
Liquid Chamber Volume (l)	11.7
Combustion Chamber Volume (l)	5.845
Liquid Reservoir Area (cm^2)	719.6
Combustion Chamber Area (cm^2)	916.3
Vent Area (cm^2)	81.
Injector Discharge Coefficient	0.75
Shot-Start Pressure (MPa)	34.
Bore Friction 0 to Muz. (MPa)	5.5
Propellant Type:	Liquid JA2

2. PROCEDURE OF STUDY

The 120-mm gun was chosen partly in response to a study by Woodley[6] on an English regenerative liquid propellant gun of the same caliber. Although the mechanical configuration of the English version is different from its U.S. counterpart, it was of interest to note the similarities and differences in the models. This study parallels Woodley[7] by varying parameters by +20%, +10%, -10%, -20%.

The following parameters, including both ballistic parameters and propellant properties, were varied one at a time by -20%, -10%, +10%, +20%.

Piston Weight
Projectile Weight
Combustion Chamber Volume
Area of Liquid Reservoir (cross-sectional)
Area of Combustion Chamber (cross-sectional)
Covolume
Vent Area
Shot Start Pressure
Bulk Modulus
Derivative of Bulk Modulus with Pressure
Chemical Energy
Specific Heat Ratio
Density
Discharge Coefficient of Liquid Injector
Discharge Coefficient Chamber to Barrel

In each case the effects on the following performance characteristics were recorded both absolutely and as percent change.

Muzzle Velocity
Maximum Liquid Pressure
Maximum Combustion Chamber Pressure
Maximum Base Pressure (base of projectile)
Maximum Acceleration
Maximum Piston Travel
Piston Velocity at Impact
Time to Ejection of Projectile
Fraction of Liquid Burned

The complete data appears in Appendix A in table form and in Appendix B as plots of percentage change in performance vs percentage change in input parameters. After viewing the data, it was noticed that the maximum liquid pressure exceeded the stipulated value of 700 MPa in several cases. In an effort to more nearly approximate realistic conditions and to study a high performance situation, each case was recomputed with the condition of a fixed maximum liquid pressure of 700 MPa. The adjustable parameter was taken to be the vent area which controls the influx of liquid fuel into the combustion chamber. The effects on performance characteristics were recorded again both absolutely and as percent change. This data appears in Appendix C.

III. RESULTS

1. 120-MM RLP GUN STANDARD CASE RESULTS

The baseline results for the 120-mm RLP gun described above are presented in Table 2. No piston damping was considered in this model, although damping is routinely included in actual hardware.

TABLE 2. 120-mm RLP Gun Standard Case Results

VARIABLE	VALUE
Muzzle Velocity (m/s)	1925.3
Maximum Liquid Pressure (MPa)	692.8
Maximum Combustion Chamber Pressure (MPa)	494.9
Maximum Base Pressure (MPa)	341.7
Maximum Acceleration (K-G)	54.3
Piston Velocity @ Impact (cm/s)	5140.4

2. EFFECTS ON MUZZLE VELOCITY

The effect of percentage change in piston weight, projectile weight, liquid volume, liquid area, chamber area and vent area on the percentage change in muzzle velocity is illustrated in Figure 2. The ballistic parameter having the greatest impact on muzzle velocity is the chamber area. Although a negative percent change in chamber area is accompanied by a significant decrease in muzzle velocity, the effect is less for a positive percent change in chamber area.

A -20% change in chamber area is associated with a -47% change in muzzle velocity. Since the chamber to reservoir area ratio (the hydraulic ratio or hydraulic difference) is not fixed, lower chamber area results in a lower hydraulic ratio. The effect is a lower reservoir pressure, lower pressure difference between the chamber and reservoir, and, thus, reduced liquid injection and lower chamber pressure. On the other hand, a +20% change in chamber area corresponded to only a 5.69% change in muzzle velocity. Although the larger chamber area results in increased pressure in the liquid, the amount of liquid entering the combustion chamber is also controlled by the vent area which was not changed.

Changes in liquid area mirror results from changes in chamber area inversely. This result is expected since increased liquid area lowers the hydraulic ratio, while decreased liquid area raises the hydraulic ratio. The other major parameters of piston mass, projectile mass, liquid volume, chamber volume, and vent area affected muzzle velocity in the +-10% range.

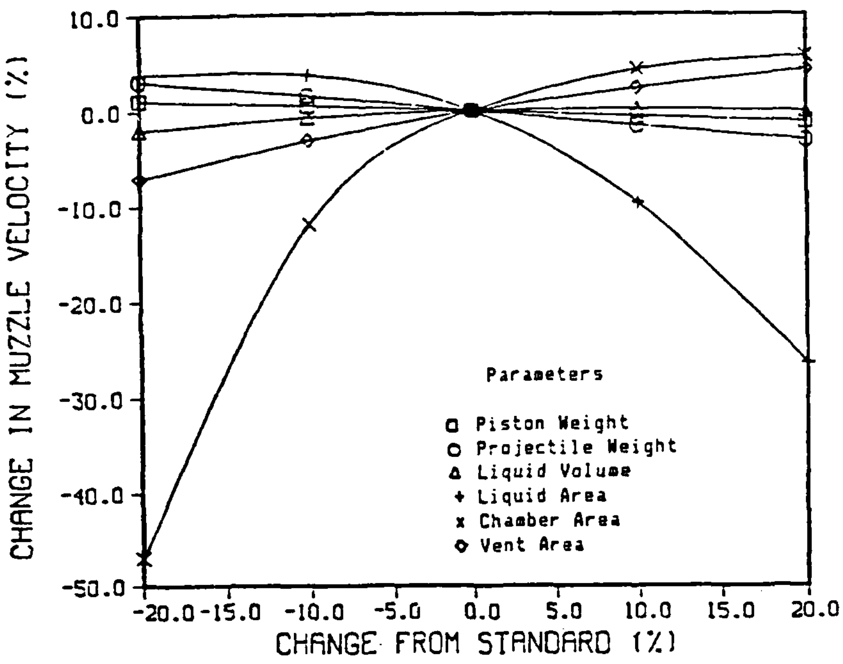

Figure 2. Percentage Change in Muzzle Velocity

3. EFFECTS ON MAXIMUM LIQUID PRESSURE

The effect of percentage change in piston weight, projectile weight, liquid volume, liquid area, chamber area and vent area on the percentage change in maximum liquid pressure is illustrated in Figure 3. The ballistic parameters having the greatest impact on maximum liquid pressure were chamber area and liquid area. This was an expected result since the hydraulic difference controls piston motion. The effect is dramatic; a -20% change in chamber area corresponded to a -86% change in maximum liquid pressure while a +20% change produced a +69% change in maximum liquid pressure. Inversely, a -20% change in liquid area gave a +86% change in maximum liquid pressure while a +20% change is associated with a -66% change in maximum liquid pressure. Other parameters having significant effect were vent area giving changes in the +-20% range and projectile mass giving changes in the +-10% range.

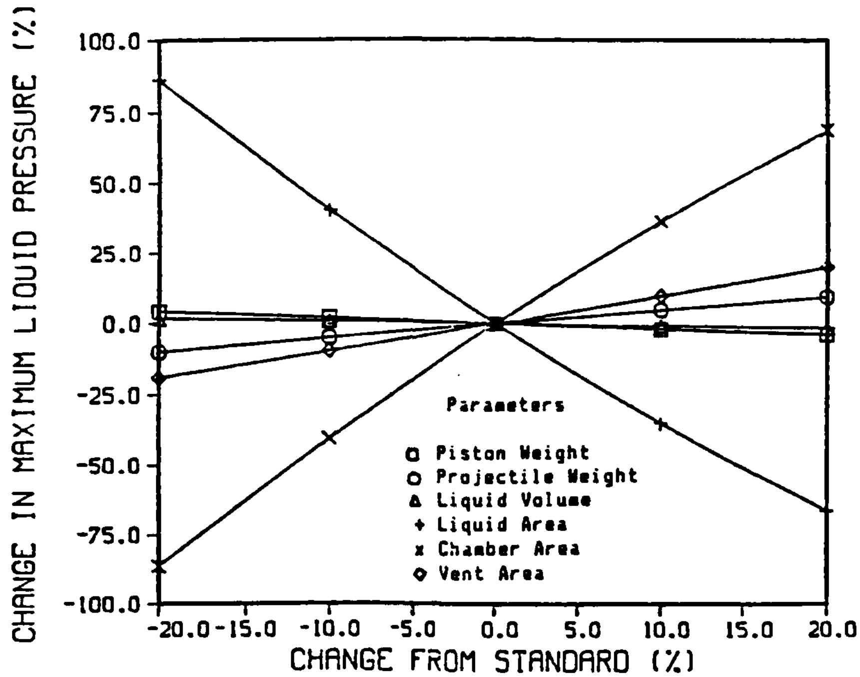

Figure 3. Percentage Change in Maximum Liquid Pressure

4. EFFECTS ON MAXIMUM COMBUSTION CHAMBER PRESSURE

The effect of percentage change in piston weight, projectile weight, liquid volume, liquid area, chamber area and vent area on the percentage change in maximum combustion chamber pressure is illustrated in Figure 4. The ballistic parameters having the greatest impact on maximum combustion chamber pressure were chamber area and liquid area. This was an expected result since these two parameters are recognized to dominate chamber pressure. A significant effect is demonstrated; a -20% change in chamber area corresponded to a -81% change in maximum combustion chamber pressure while a +20% change produced a +34% change in maximum combustion chamber pressure. Inversely, a -20% change in liquid area gave a +33% change in maximum combustion chamber pressure while a +20% change is associated with a -57% change in maximum combustion chamber pressure. Other parameters having significant effect were vent area giving changes in the +-20% range and projectile mass giving changes in the +-10% range.

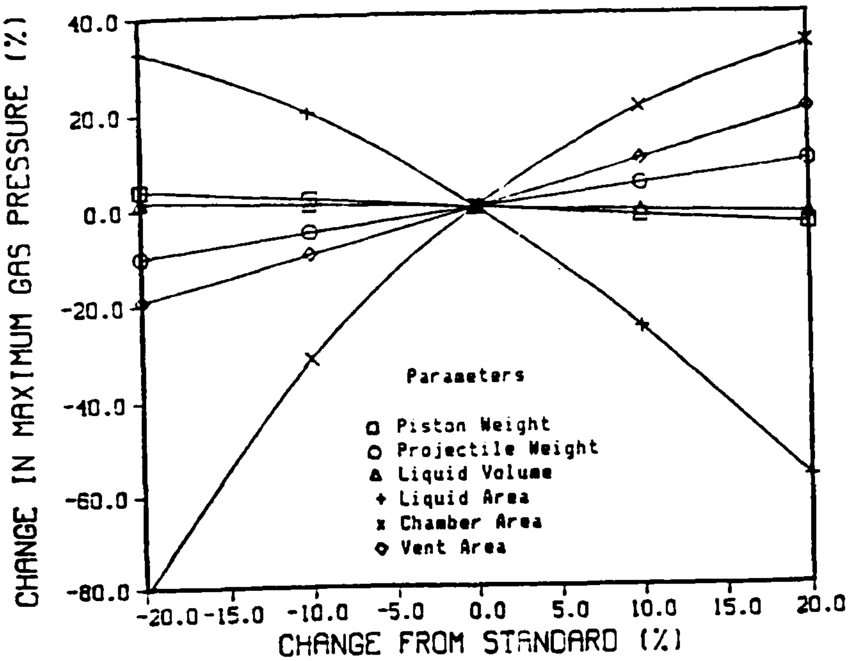

Figure 4. Percentage Change in Maximum Combustion Chamber Pressure

5. SUMMARY VARIATIONS

Table 3 summarizes the major ballistic parameters and the range of corresponding percentage changes in maximum liquid pressure, maximum combustion chamber pressure (gas), and velocity. As already noted, the controlling effect of liquid and chamber areas on maximum liquid and combustion chamber pressures was expected. The hydraulic ratio increases with either increased chamber area or decreased liquid area. Similarly, the hydraulic ratio decreases with decreased chamber area or increased liquid area. Vent area controls the amount of fuel entering the combustion chamber and affects pressures as expected. The volume of liquid propellant has only a minor effect on the system unless there is not enough available to give sufficient impetus to the projectile.

It is, perhaps, more interesting to note the changes in projectile velocity. First, velocity is not substantially affected by projectile (shot) or piston mass in the range +-20%, a fact which be suprising at first glance. However,

$$v = \sqrt{\frac{2}{m_p} KE}$$

where KE is the kinetic energy and M_p is the mass of the projectile. Also,

$$KE = A_B \int P_s \, dx$$

if P_s increases uniformly by 10%, KE increases by 10%. Since M_p is increased by 20%,

$$v' \sim \sqrt{\frac{1.1}{1.2}}$$

or, $v' \sim 0.957v$. That is, the expected change in velocity for a +20% change in shot mass is -4.2% for a uniform increase in P_s. Since P_s does not increase uniformly, the expected change in velocity is less than -4.3%, a value which compares favorably with the results of the study. Secondly, projectile velocity is most affected by chamber and liquid area changes. Again, the dominant effect of the ratio of chamber area to liquid area is illustrated.

6. OTHER PARAMETERS

The other performance characteristics are not addressed in this report since they are of minor interest. Maximum acceleration parallels maximum base pressure; maximum piston travel has an upper limit imposed physically by the gun; projectile ejection time is within a millisecond; the fraction of liquid burned is 1.0 in all but three cases.

TABLE 3. Summary Of Effects

	PMAX LP	PMAX GAS	VEL
-20% / +20%			
CHAMBER AREA	-86/+69	-81/+34	-47/+6
LIQUID AREA	+86/-67	+33/-57	+4/-26
VENT AREA	-19/+20	-19/+20	-7/+4
SHOT MASS	10/+10	-10/+10	+3/-3
PISTON MASS	+4/-4	+4/-4	+1/-1
LP VOLUME	1.6/-1.5	1.7/-1.6	-2/ .06

A complete listing of all parameters varied recorded both absolutely and as percentage change along with the corresponding absolute and percentage change in performance characteristics for the 120-mm regenerative liquid propellant gun can be found in Appendix A. A visual presentation of the results in the form of percentage change graphs can be found in Appendix B. For each parameter varied two graphs are presented:

1) Percentage change in parameter vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

2) Percentage change in parameter vs. percentage changes in muzzle velocity and maximum piston velocity.

IV. CONSTRAINT ON MAXIMUM LIQUID PRESSURE

1. PROCEDURE

In studies of gun systems a common procedure is to fix chamber pressure and view parameter changes relative to this condition. The analog to the solid propellant case in the regenerative liquid propellant gun is to fix the pressure in the liquid reservoir, essentially the breech pressure, and analyze the effect of parameter changes with a constraint on liquid pressure. Liquid pressure can be controlled by the vent area, analogous to the web in solid propellant. A fixed maximum liquid pressure of 700 MPa was chosen for the 120-mm gun described in this report. This constraint should reflect a high performance regime for the system described. Parameter changes in the +-20% range were then analyzed with the constraint of a fixed maximum liquid pressure of 700 MPa, a value controlled by varying vent area. The vent areas used are given in Table 4.

TABLE 4. Adjusted Vent Areas

PARAMETER	PERCENT CHANGE	VENT AREA (cm^2)
PISTON WEIGHT	-20.0	78.5
PISTON WEIGHT	-10.0	80.0
PISTON WEIGHT	10.0	83.5
PISTON WEIGHT	20.0	85.3
PROJECTILE WEIGHT	-20.0	91.0
PROJECTILE WEIGHT	-10.0	86.2
PROJECTILE WEIGHT	10.0	77.97
PROJECTILE WEIGHT	20.0	74.48

TABLE 4. Adjusted Vent Areas (Con't)

CHAMBER VOLUME	-20.0	77.5
CHAMBER VOLUME	-10.0	80.0
CHAMBER VOLUME	10.0	83.6
CHAMBER VOLUME	20.0	85.3
LIQUID VOLUME	-20.0	80.5
LIQUID VOLUME	-10.0	81.2
LIQUID VOLUME	10.0	82.5
LIQUID VOLUME	20.0	83.1
LIQUID AREA	-20.0	41.22
LIQUID AREA	-10.0	57.45
LIQUID AREA	10.0	127.1
LIQUID AREA	20.0	NONE
CHAMBER AREA	-20.0	NONE
CHAMBER AREA	-10.0	139.9
CHAMBER AREA	10.0	59.4
CHAMBER AREA	20.0	47.18

2. RESULTS

Since controlling vent area controls maximum liquid pressure, the performance characteristic of interest was the muzzle velocity. As pictured in Figure 5, all liquid and chamber area changes resulted in a decrease in muzzle velocity except a -10% change in chamber area (or a +10% increase in liquid area). This may suggest slightly improved performance in the gun system described by decreasing chamber area 10%. It is also noted that it was impossible to reach a maximum liquid pressure of 700 MPa for the -20% chamber area and +20% liquid area cases. Therefore, the graphs reflect the effect utilizing the maximum possible liquid pressure. Statistics can be found in Appendix C.

Changes in chamber volume, liquid volume, piston mass, and projectile mass relate to changes in muzzle velocity in the +- 5% range. Now, as expected, lighter projectiles travel faster, and vice versa.

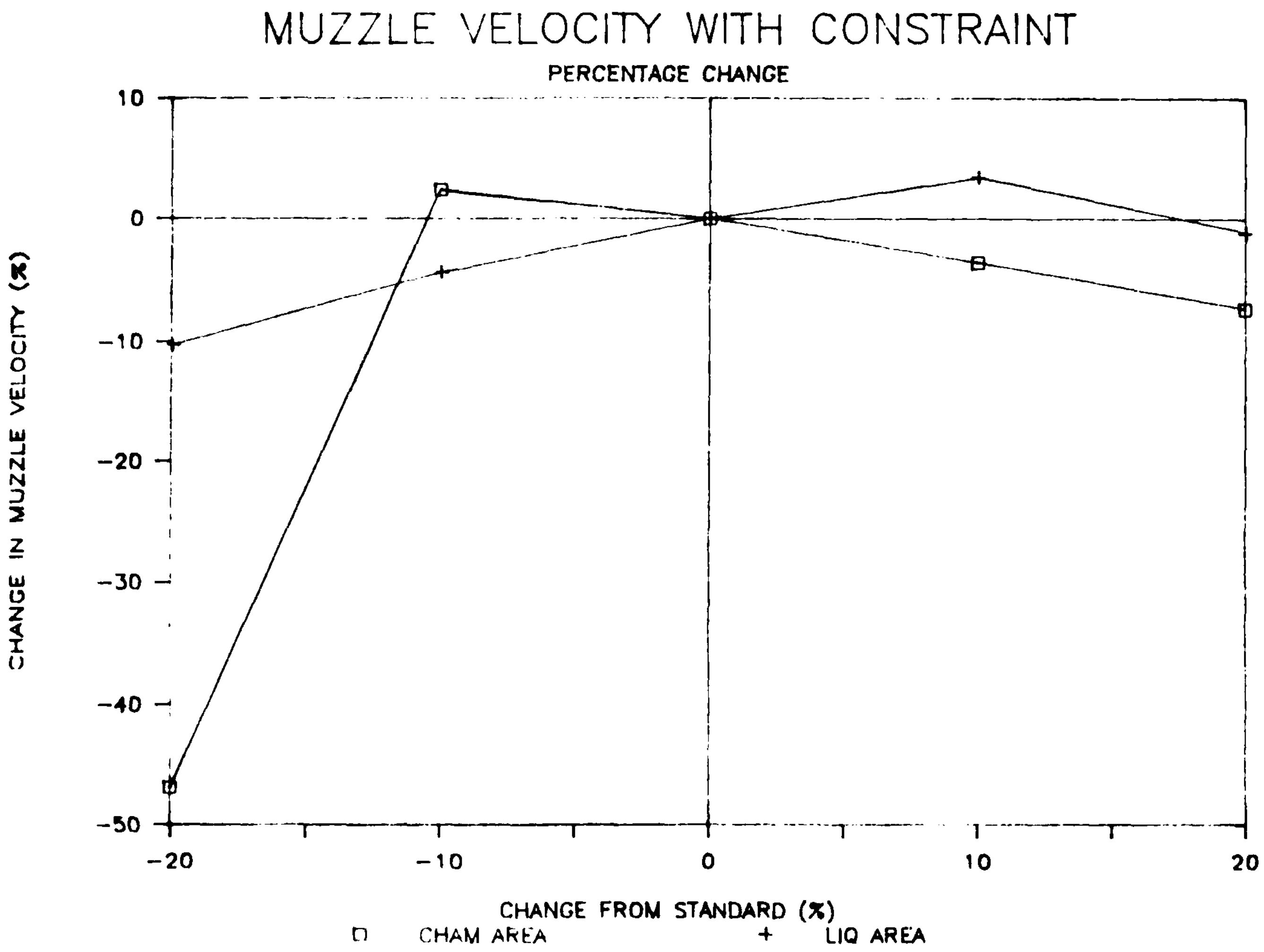

Figure 5. Percentage Change in Muzzle Velocity with Constraint Compared to Change in Area

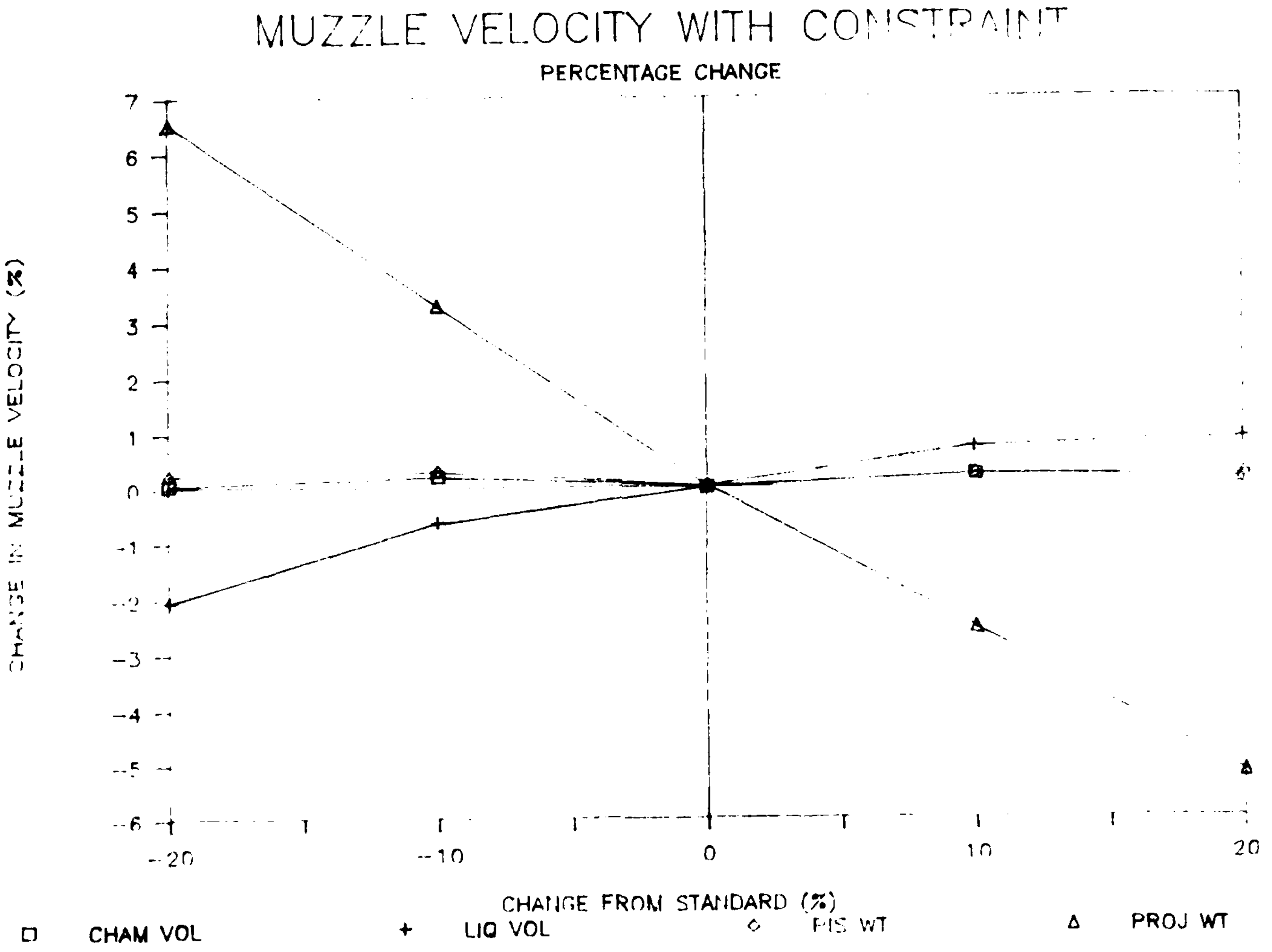

Figure 6. Percentage Change in Muzzle Velocity with Constraint Compared to Volume and Mass Changes

V. DIFFERENTIAL COEFFICIENTS

It may be desirable to approximate expected performance characteristics for percentage changes other than those specifically listed in the appendix. Therefore, the five data points for percentage changes of -20%, -10%, 0%, +10%, +20% were successfully fitted with a fourth degree polynomial to allow for interpolation in the range -20% to +20%. The table below gives the ...

for the coefficients of $Ax^4+Bx^3+Cx^2+Dx+E=0$. In all cases E=0 since its value was on the order 10^{-14}.

TABLE 5. Differential Coefficients: Quartic Fit

Variation of:	Ax^4	Bx^3	Cx^2	Dx
Piston Weight with Muzzle Velocity	.84	-.06	-.04	-.05
Piston Weight with Max Liquid Pres	-.12	-.24	.45	-.20
Piston Weight with Max Com Ch Pres	-.08	-.02	.04	-.20
Proj Weight with Muzzle Velocity	.35	.35	-.01	-.15
Proj Weight with Max Liquid Pres	-.60	.01	-.07	.49
Proj Weight with Max Com Ch Pres	.17	.00	-.08	.49
Liquid Vol with Muzzle Velocity	-.04	.09	-.24	.04
Liquid Vol with Max Liquid Pres	.12	-.24	.01	-.08
Liquid Vol with Max Com Ch Pres	.17	.00	.01	-.08
Vent Area with Muzzle Velocity	1.02	.37	-.38	.26
Vent Area with Max Liquid Pres	.60	.12	.12	.97
Vent Area with Max Com Ch Pres	.25	.12	.13	.98

Liquid area and combustion chamber area parameters did not fit well with a fourth degree polynomial. Therefore, the points for -20%, -10%, 0% were fitted with a quadratic function, $Ax^2+Bx+C=0$ while the points for 0%, 10%, 20% were fitted with another quadratic function. In all cases the constant was on the order of 10^{-14} and is considered zero.

TABLE 6. Differential Coefficients: Quadratic Fit

Variation of:	Case of -20%,-10%,0% Ax^2	Case of -20%,-10%,0% Bx	Case of 0%,10%,20% Ax^2	Case of 0%,10%,20% Bx
Liquid Area with Muzzle Velocity	-1.72	-.55	-3.57	-.61
Liquid Area with Max Liquid Pres	2.82	-3.75	1.39	-3.60
Liquid Area with Max Com Ch Pres	-3.62	-2.37	-3.16	-2.21
Chamber Area with Muzzle Velocity	-11.53	.04	-1.47	.58
Chamber Area with Max Liquid Pres	-2.69	3.78	-2.05	3.86
Chamber Area with Max Com Ch Pres	-9.22	2.21	-3.78	2.44

VI. CONCLUSIONS

A sensitivity study has been completed using a hypothetical 120-mm regenerative liquid propellant tank gun. Like its English counterpart, the model has proven quite insensitive to many parameters. Specifically, for parameter changes in the range +-20% the model showed changes of less than 2%, sometimes significantly less, to parameter changes of shot start pressure, bulk modulus, derivative of bulk modulus with pressure. Although piston mass changes gave performance changes of the order of +-5% in pressures, change in muzzle velocity was less than +-1%. Projectile mass changes gave +-10% changes in pressures, but only +-3% changes in muzzle velocity. As expected, changes in the cross-sectional area of the liquid reservoir and combustion chamber yielded the greatest changes in both pressures and muzzle velocity, +-60% or more. Thus, the system is driven by the hydraulic difference, the ratio of chamber area to liquid area, which controls the motion of the piston. All other parameters are of secondary consideration.

The second part of the study reflected an analog to some studies of solid propellant gun systems by fixing pressure and viewing parameter changes under this condition. Thus, maximum liquid pressure was taken to be 700 MPa and was controlled by varying vent area. Parameter changes in the +-20% range were analyzed with this constraint. An analysis of the effects on muzzle velocity indicate higher velocity for this system with a -10% change in chamber area or a +10% change in liquid area. Other parameter changes have little effect.

Although the study considered parameter changes of only +-20% and +-10%, a computation of differential coefficients for the changes will enable the researcher to interpolate expected performance characteristics within this range. As with any analysis of differential coefficients, extrapolation outside the +-20% range may not be valid.

In general, results in the +-1% range should always be viewed with some caution since discretization and round-off error may affect small changes. Also, piston velocity at impact was taken from a table of incremental time steps and may not precisely reflect the velocity obtained in the model. Finally, changes in parameters chosen in this study may not at all times be reasonable expectations physically.

VII. FURTHER INVESTIGATIONS

Although the sensitivity study provides insight into the regenerative liquid propellant interior ballistic process gun using the Coffee code, it would be instructive to compare the results to the other existing regenerative liquid propellant gun codes to more clearly understand assumptions and differences in the underlying equations. As data from actual firings of the gun become available, a cross-checking of expected results with actual results will serve to further illuminate the underlying theoretical basis for regenerative liquid propellant guns.

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Appendix A

The statistics for parameter change vs. change in performance characteristics are presented both absolutely and as percentage change.

120MM REGENERATIVE LIQUID PROPELLANT GUN
SENSITIVITY STUDY
RLGD CODE

Piston	Weight	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ 80
g	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
61326.4	-20.0	1946.8	1.12	721.6	4.16	515.3	4.12	364.2	6.58	57.9	6.63	20.342	-0.01	5192.2	1.01	6.96	-3.71	1.00
68992.2	-10.0	1935.3	0.52	706.9	2.04	504.9	2.02	352.6	3.19	56.0	3.13	20.361	0.08	5158.7	0.36	7.10	-1.83	1.00
76658.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
84323.8	10.0	1914.2	-0.58	679.3	-1.95	485.3	-1.94	331.5	-2.99	52.6	-3.13	20.349	0.02	5106.0	-0.67	7.36	1.71	1.00
91989.6	20.0	1903.3	-1.14	666.2	-3.84	476.0	-3.82	321.7	-5.85	51.0	-6.08	20.352	0.04	5084.3	-1.09	7.48	3.43	1.00

Proj.	Weight	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ 80
g	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
5696.0	-20.0	1985.2	3.11	622.7	-10.12	444.8	-10.12	290.8	-14.90	57.5	5.89	20.356	0.06	4883.1	-5.01	6.98	-3.54	1.00
6408.0	-10.0	1955.2	1.55	658.3	-4.98	470.2	-4.99	316.7	-7.32	55.8	2.76	20.343	-0.00	5013.9	-2.46	7.11	-1.71	1.00
7120.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
7832.0	10.0	1895.1	-1.57	726.3	4.84	518.8	4.83	365.9	7.08	52.9	-2.58	20.350	0.03	5247.8	2.09	7.34	1.55	1.00
8544.0	20.0	1865.8	-3.09	758.8	9.53	542.0	9.52	389.6	14.02	51.7	-4.79	20.354	0.05	5366.9	4.41	7.45	3.04	1.00

Chamber	Volume	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ 80
cc	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
4676.0	-20.0	1948.9	1.23	726.2	4.82	518.3	4.73	362.7	6.15	57.7	6.26	20.342	-0.01	5177.8	0.73	7.02	-2.88	1.00
5260.5	-10.0	1935.5	0.53	708.7	2.30	506.1	2.26	351.8	2.96	55.9	2.95	20.354	0.05	5168.3	0.54	7.13	-1.44	1.00
5845.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
6429.5	10.0	1913.6	-0.61	678.0	-2.14	484.4	-2.12	332.2	-2.78	52.7	-2.95	20.361	0.08	5139.5	-0.02	7.33	1.38	1.00
7014.0	20.0	1903.2	-1.15	664.5	-4.08	474.9	-4.04	323.6	-5.30	51.3	-5.52	20.350	0.03	5084.0	-1.10	7.42	2.65	1.00

Liquid	Volume	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ 80
cc	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
9360.0	-20.0	1887.8	-1.95	704.0	1.62	503.3	1.70	351.4	2.84	55.8	2.76	16.280	-19.98	5280.1	2.72	7.14	-1.27	1.00
10530.0	-10.0	1911.9	-0.70	698.2	0.78	499.0	0.83	346.4	1.38	55.0	1.29	18.322	-9.94	5210.9	1.37	7.18	-0.72	1.00
11700.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
12870.0	10.0	1929.1	0.20	687.6	-0.75	490.9	-0.81	337.2	-1.32	53.5	-1.47	22.386	10.04	5072.2	-1.33	7.28	0.72	1.00
14040.0	20.0	1924.2	-0.06	682.6	-1.47	487.1	-1.58	332.9	-2.58	52.8	-2.76	24.425	20.06	4992.4	-2.88	7.34	1.44	1.00

Liquid	Area	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ 80
cm^2	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
575.7	-20.0	1999.8	3.87	1290.9	86.33	657.4	32.83	397.4	16.30	63.3	16.57	27.156	33.48	12366.7	140.58	6.84	-5.48	1.00
647.6	-10.0	1996.9	3.72	972.5	40.37	594.1	20.04	382.6	11.97	60.9	12.15	23.256	14.31	8292.7	61.32	6.91	-4.42	1.00
719.6	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
791.6	10.0	1739.0	-9.68	452.6	-34.67	370.0	-25.24	275.2	-19.46	43.5	-19.89	17.802	-12.50	2732.0	-46.85	7.92	9.46	1.00
863.5	20.0	1415.8	-26.46	232.0	-66.51	214.0	-56.76	175.6	-48.61	27.4	-49.54	9.274	-54.41	1098.2	-78.64	9.52	31.69	0.56

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Chamber	Area	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
cm^2	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
733.0	-20.0	1021.1	-46.76	95.0	-86.29	93.2	-81.17	84.6	-75.24	12.7	-76.61	5.829	-71.35	544.9	-89.40	13.12	81.47	0.28
824.7	-10.0	1695.5	-11.93	412.7	-40.43	339.8	-31.34	247.8	-27.48	39.1	-27.99	19.249	-5.38	2968.2	-42.26	8.36	15.60	0.94
916.3	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
1007.9	10.0	2008.4	4.32	946.2	36.58	597.1	20.65	401.4	17.47	63.9	17.68	20.355	0.05	6922.6	34.67	6.69	-7.52	1.00
1099.6	20.0	2034.9	5.69	1171.4	69.08	662.0	33.76	439.0	28.48	70.0	28.91	20.350	0.03	8365.4	62.74	6.39	-11.62	1.00

Co volume		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
cc/g	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
0.7968	-20.0	1870.5	-2.85	641.5	-7.40	458.2	-7.42	319.8	-6.41	50.8	-6.45	20.357	0.06	4975.9	-3.20	7.38	2.10	1.00
0.8964	-10.0	1897.0	-1.47	666.1	-3.85	475.8	-3.86	330.4	-3.31	52.5	-3.31	20.354	0.05	5049.2	-1.77	7.31	1.05	1.00
0.9960	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
1.0956	10.0	1953.8	1.48	721.8	4.19	515.5	4.16	353.8	3.54	56.2	3.50	20.354	0.05	5237.4	1.89	7.15	-1.11	1.00
1.1952	20.0	1984.6	3.08	753.3	8.73	537.9	8.69	366.9	7.37	58.3	7.37	20.354	0.05	5322.0	3.53	7.07	-2.21	1.00

Vent	Area	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
cm^2	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
64.8	-20.0	1789.9	-7.03	561.1	-19.01	400.0	-19.18	298.6	-12.61	47.3	-12.89	20.937	2.91	3572.8	-30.50	7.61	5.20	1.00
72.9	-10.0	1865.7	-3.10	626.1	-9.63	446.9	-9.70	320.8	-6.12	50.9	-6.26	20.642	1.46	4347.1	-15.43	7.40	2.38	1.00
81.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
89.1	10.0	1970.6	2.35	761.2	9.87	544.2	9.96	361.4	5.77	57.5	5.89	20.062	-1.39	5929.9	15.36	7.08	-2.05	1.00
97.2	20.0	2008.2	4.31	832.3	20.14	595.3	20.29	380.3	11.30	60.5	11.42	19.796	-2.69	6716.3	30.66	6.96	-3.76	1.00

Sh-Start	Press.	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
MPa	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
27.2	-20.0	1920.2	-0.26	687.4	-0.78	491.0	-0.79	337.0	-1.38	53.5	-1.47	20.349	0.02	5132.1	-0.16	7.24	0.11	1.00
30.6	-10.0	1922.0	-0.17	690.0	-0.40	492.9	-0.40	339.2	-0.73	53.9	-0.74	20.359	0.07	5136.2	-0.08	7.24	0.06	1.00
34.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
37.4	10.0	1927.1	0.09	695.6	0.40	496.8	0.38	344.1	0.70	54.7	0.74	20.349	0.02	5144.9	0.09	7.22	-0.11	1.00
40.8	20.0	1929.4	0.21	698.5	0.82	498.8	0.79	346.4	1.38	55.0	1.29	20.342	-0.01	5148.8	0.16	7.22	-0.17	1.00

Mol.	Weight	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
g/mole	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
19.8920	-20.0	1925.7	0.02	693.0	0.03	495.0	0.02	341.8	0.03	54.3	0.00	20.357	0.06	5142.0	0.03	7.23	-0.06	1.00
22.3785	-10.0	1925.2	-0.01	692.9	0.01	495.0	0.02	341.7	0.00	54.3	0.00	20.349	0.02	5141.2	0.02	7.23	-0.06	1.00
24.8650	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
27.3515	10.0	1923.8	-0.08	691.7	-0.16	494.1	-0.16	340.9	-0.23	54.1	-0.37	20.342	-0.01	5138.7	-0.03	7.24	0.06	1.00
29.8380	20.0	1923.5	-0.09	692.6	-0.03	494.8	-0.02	341.5	-0.06	54.3	0.00	20.358	0.07	5139.4	-0.02	7.23	0.00	1.00

Bulk	Modulus	Muzzle	Velocity	Max. Liq.	Press.	Max. Comb	Pres.	Max. Base	Pres.	Max.	Accel.	Max. Pist	Travel	Pist. Vel@	Impact	Time @	Eject	z @ BO
MPa	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
4082.8	-20.0	1925.7	0.02	695.6	0.40	496.8	0.38	339.0	-0.79	53.8	-0.92	20.351	0.03	5124.6	-0.31	7.31	1.05	1.00
4593.2	-10.0	1925.3	0.00	694.1	0.19	495.7	0.16	340.4	-0.38	54.1	-0.37	20.361	0.08	5140.2	-0.00	7.26	0.44	1.00
5103.5	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
5613.9	10.0	1924.7	-0.03	691.9	-0.13	494.2	-0.14	342.9	0.35	54.5	0.37	20.353	0.04	5141.2	0.02	7.20	-0.44	1.00
6124.2	20.0	1923.6	-0.09	691.0	-0.26	493.6	-0.26	343.9	0.64	54.6	0.55	20.354	0.05	5141.0	0.01	7.17	-0.83	1.00

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B. Mod. Derv. dBM/dP	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
6.574	-20.0	1924.9	-0.02	692.9	0.01	494.8	-0.02	339.7	-0.59	53.9	-0.74	20.351	0.03	5135.9	-0.09	7.24	0.17	1.00
7.396	-10.0	1925.2	-0.01	693.0	0.03	495.0	0.02	340.8	-0.26	54.1	-0.37	20.348	0.02	5138.5	-0.04	7.24	0.06	1.00
8.217	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
9.039	10.0	1924.7	-0.03	692.8	0.00	494.9	0.00	342.6	0.26	54.4	0.18	20.359	0.07	5142.8	0.05	7.22	-0.11	1.00
9.861	20.0	1925.3	0.00	692.7	-0.01	494.9	0.00	343.4	0.50	54.6	0.55	20.342	-0.01	5145.0	0.09	7.22	-0.17	1.00

Chemical Energy joules	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
4053.4	-20.0	1724.4	-10.43	560.4	-19.11	400.3	-19.11	281.9	-17.50	44.6	-17.86	20.342	-0.01	4616.2	-10.20	7.84	8.46	1.00
4560.0	-10.0	1827.7	-5.07	626.6	-9.56	447.5	-9.58	311.9	-8.72	49.5	-8.84	20.350	0.03	4890.2	-4.87	7.51	3.87	1.00
5066.7	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
5573.4	10.0	2017.6	4.79	759.0	9.56	542.1	9.54	371.2	8.63	59.0	8.66	20.347	0.01	5382.1	4.70	6.99	-3.37	1.00
6080.0	20.0	2105.2	9.34	825.7	19.18	589.8	19.18	400.6	17.24	63.8	17.50	20.353	0.04	5600.7	8.96	6.77	-6.36	1.00

Sp. Heat Ratio Cp/Cv	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
1.103	-10.0	1390.6	-27.77	362.4	-47.69	259.1	-47.65	184.6	-45.98	28.9	-46.78	20.360	0.08	3772.8	-26.60	9.43	30.37	1.00
1.225	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
1.348	10.0	2260.2	17.39	969.3	39.91	691.8	39.79	477.5	39.74	76.2	40.33	20.352	0.04	5960.9	15.96	6.34	-12.33	1.00
1.470	20.0	2499.1	29.80	1205.1	73.95	859.3	73.63	597.4	74.83	95.6	76.06	20.342	-0.01	6536.9	27.17	5.84	-19.30	1.00

Liquid Density g/cc	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
1.144	-20.0	1774.1	-7.85	549.3	-20.71	392.7	-20.65	286.4	-16.18	45.3	-16.57	20.350	0.03	5192.5	1.01	7.76	7.25	1.00
1.287	-10.0	1852.2	-3.80	619.9	-10.52	442,9	-10.51	314.1	-8.08	49.8	-8.29	20.346	0.01	5154.6	0.28	7.47	3.32	1.00
1.430	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
1.573	10.0	1991.8	3.45	768.2	10.88	548.6	10.85	368.9	7.96	58.7	8.10	20.346	0.01	5120.4	-0.39	7.02	-2.93	1.00
1.176	20.0	2056.0	6.79	846.6	22.20	604.4	22.13	395.9	15.86	63.0	16.02	20.345	0.00	5123.8	-0.32	6.84	-5.48	1.00

Disc. Coef. Liq. Inj	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
0.600	-20.0	1794.3	-6.80	566.0	-18.30	403.4	-18.49	301.6	-11.74	47.8	-11.97	20.353	0.04	3485.4	-32.20	7.57	4.65	1.00
0.675	-10.0	1867.9	-2.98	628.9	-9.22	448.8	-9.32	322.5	-5.62	51.2	-5.71	20.357	0.06	4287.8	-16.59	7.38	2.10	1.00
0.750	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
0.835	10.0	1972.8	2.47	766.0	10.57	547.5	10.63	361.3	5.74	57.4	5.71	20.36	0.01	6128.0	19.21	7.10	0.98	1.00
0.900	20.0	2002.0	3.98	823.2	18.82	588.8	18.97	375.3	9.83	59.7	9.95	20.361	0.01	6878.5	33.81	7.01	0.97	1.00

Disc. Coef. Ch.>Bore	%	Muzzle m/s	Velocity %	Max. Liq. MPa	Press. %	Max. Comb MPa	Pres. %	Max. Base MPa	Pres. %	Max. Kgs	Accel. %	Max. Pist cm	Travel %	Pist. Vel@ cm/s	Impact %	Time @ ms	Eject %	z @ BO
0.800	-20.0	1919.3	-0.31	744.8	7.51	532.4	7.58	332.6	-2.66	52.8	-2.76	20.347	0.01	5411.9	5.28	7.27	0.50	1.00
0.900	-10.0	1922.1	-0.17	714.9	3.19	510.7	3.19	337.6	-1.20	53.6	-1.29	20.343	-0.00	5256.4	2.26	7.25	0.22	1.00
1.000	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00

Appendix B

A graphic presentation of the results in Appendix A follows. For each parameter change two graphs are presented:

1) Percentage change in parameter vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

2) Percentage change in parameter vs. percentage changes in muzzle velocity and maximum piston velocity.

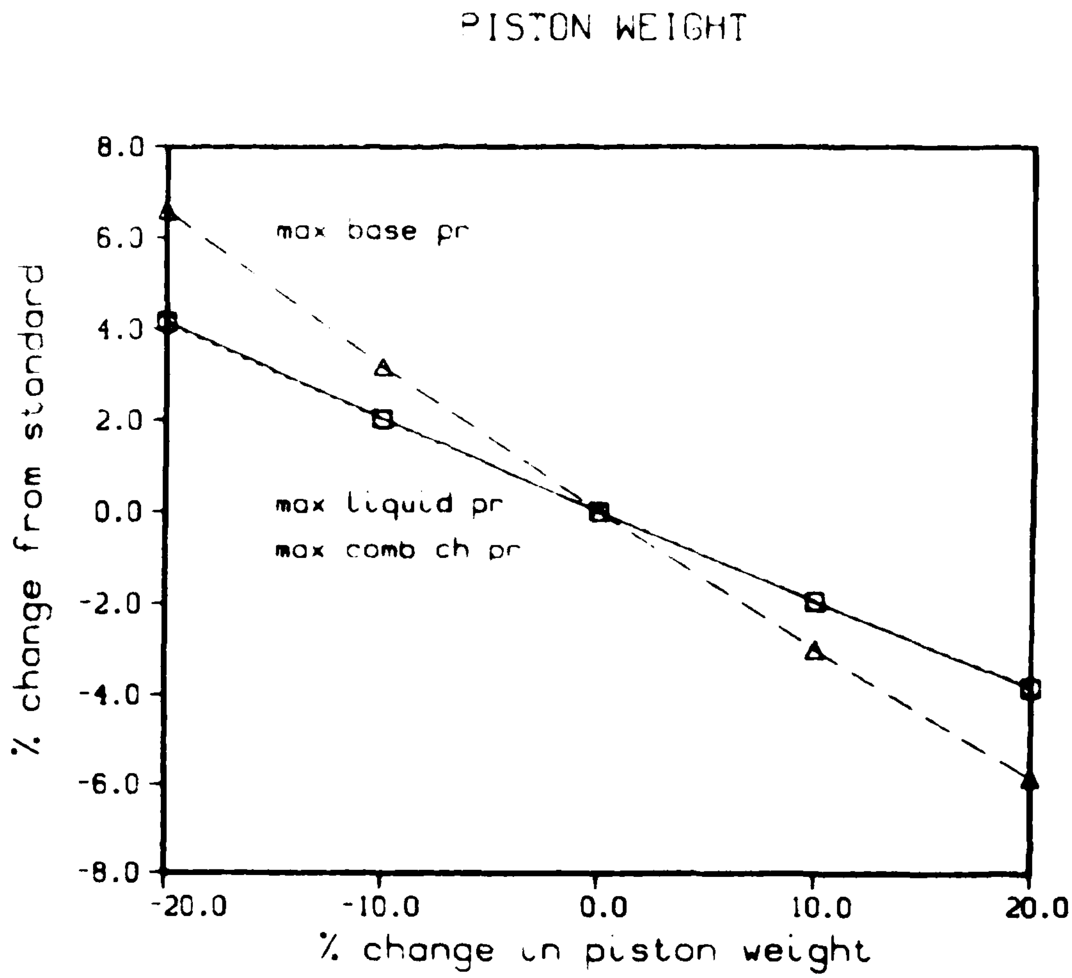

Figure B-1. Percentage change in piston weight vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

PISTON WEIGHT

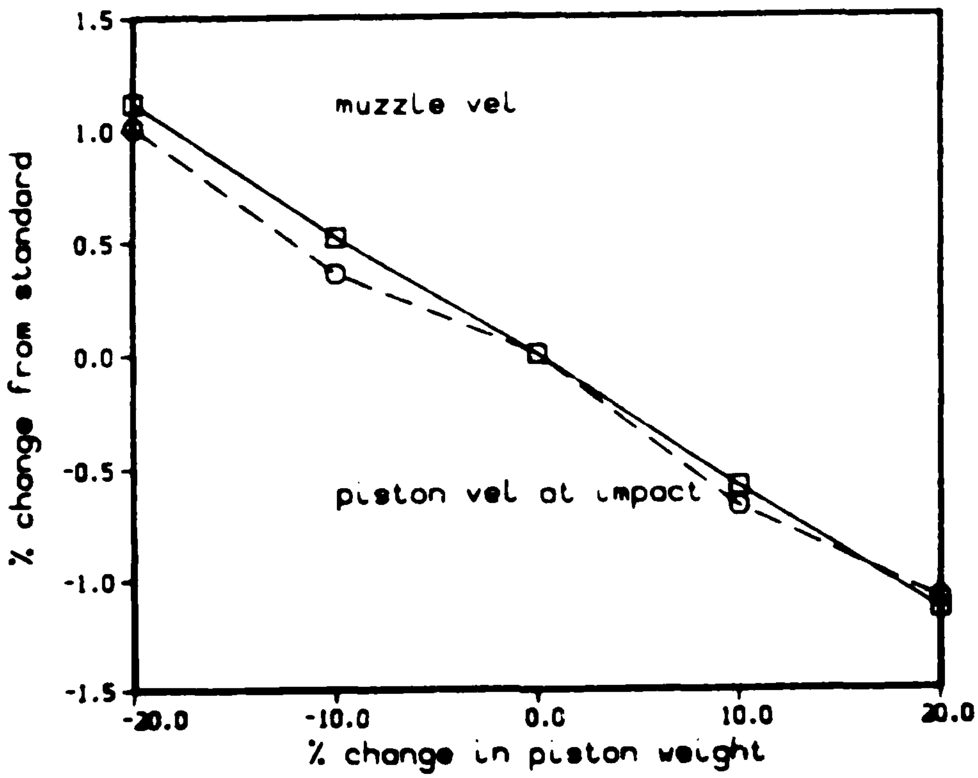

Figure B-2. Percentage change in piston weight vs. percentage changes in muzzle velocity and maximum piston velocity.

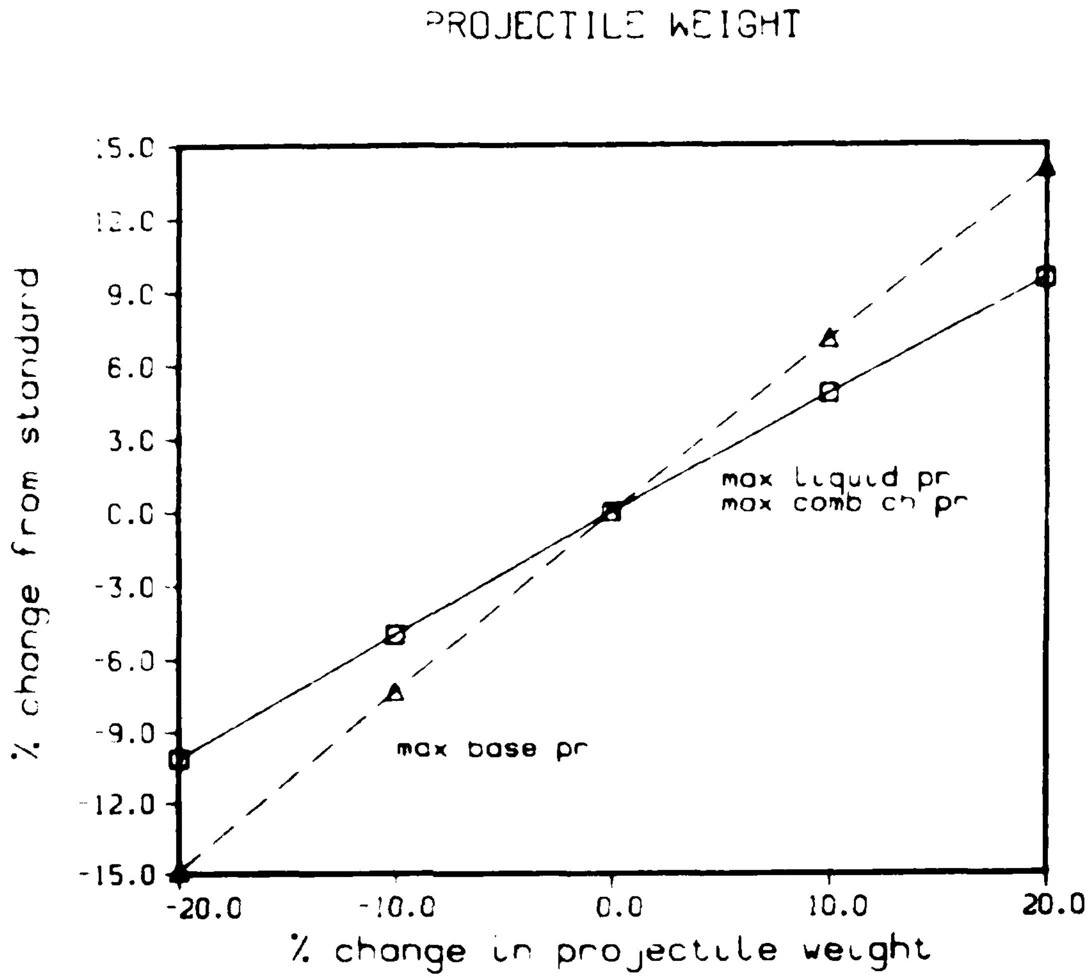

Figure B-3. Percentage change in projectile weight vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

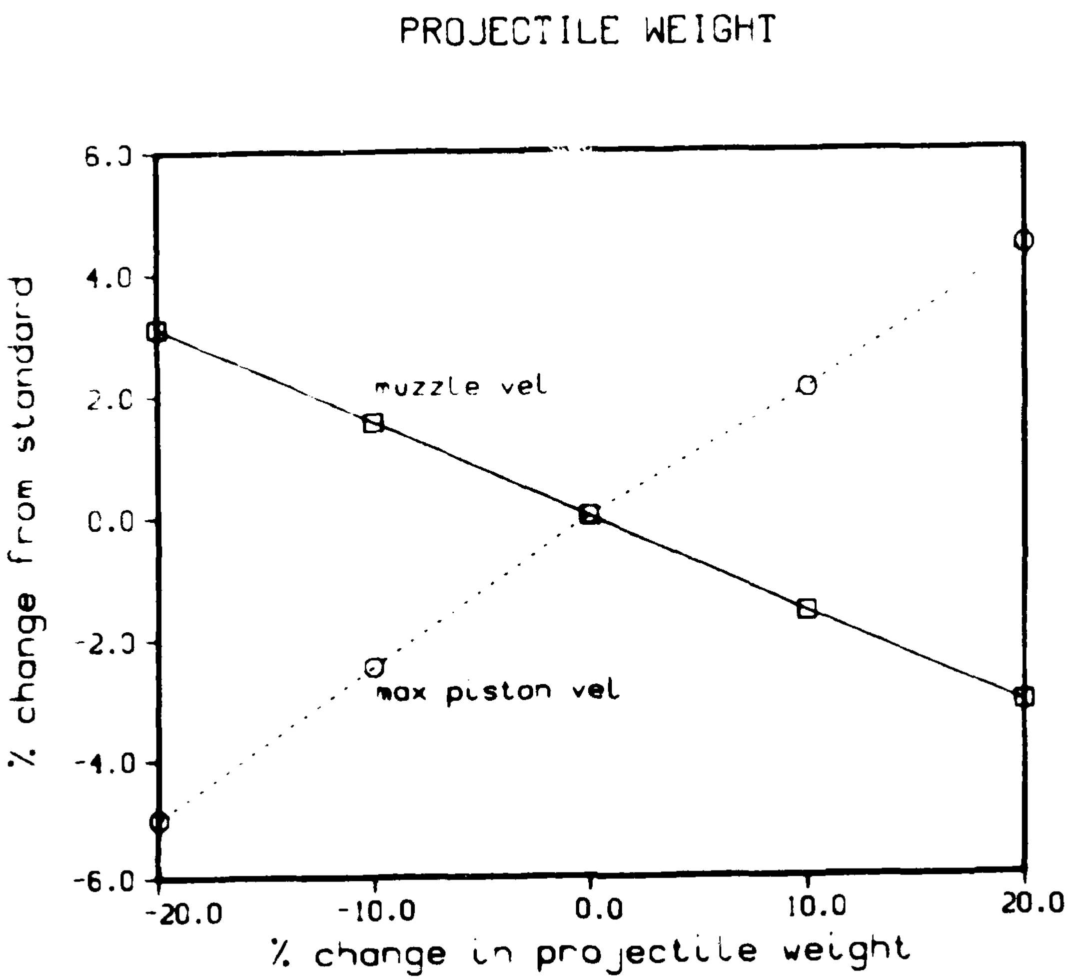

Figure B-4. Percentage change in projectile weight vs. percentage changes in muzzle velocity and maximum piston velocity.

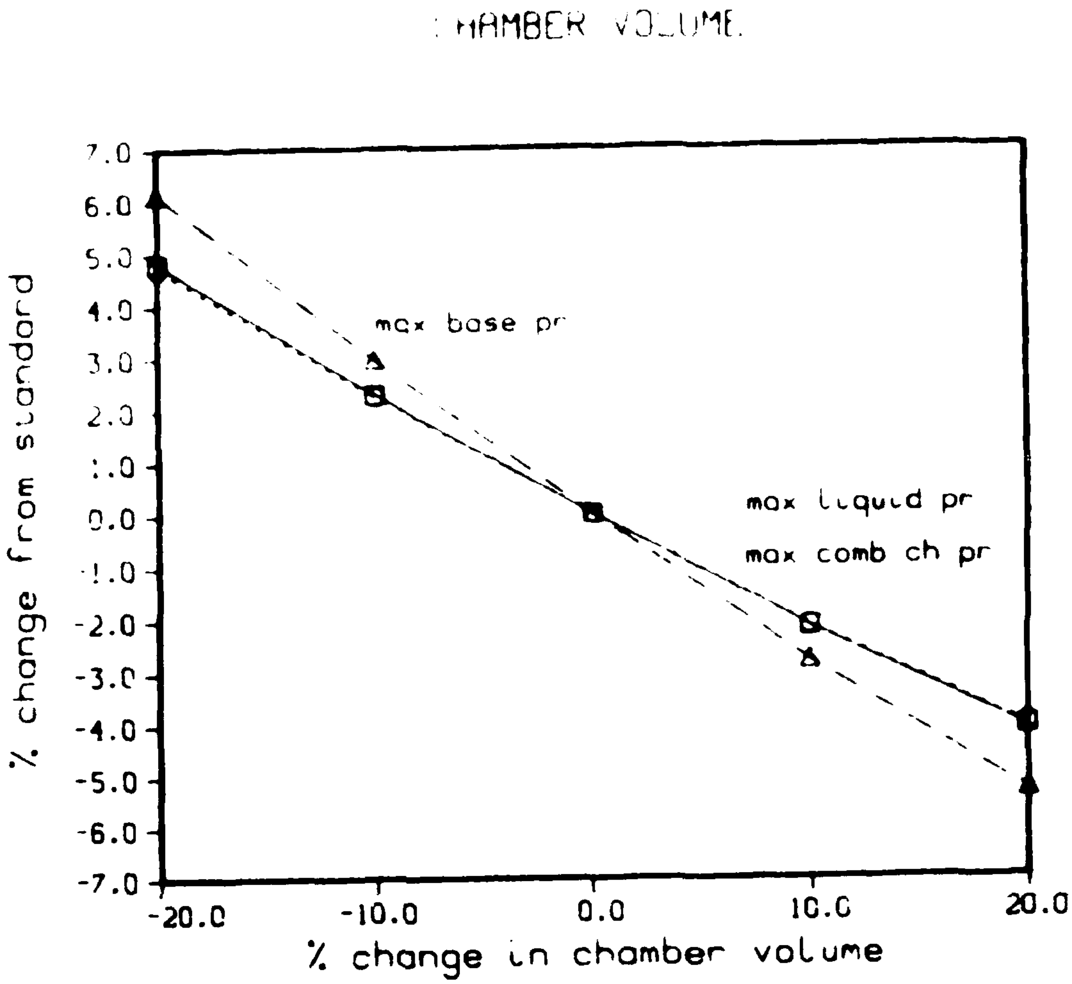

Figure B-5. Percentage change in chamber volume vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

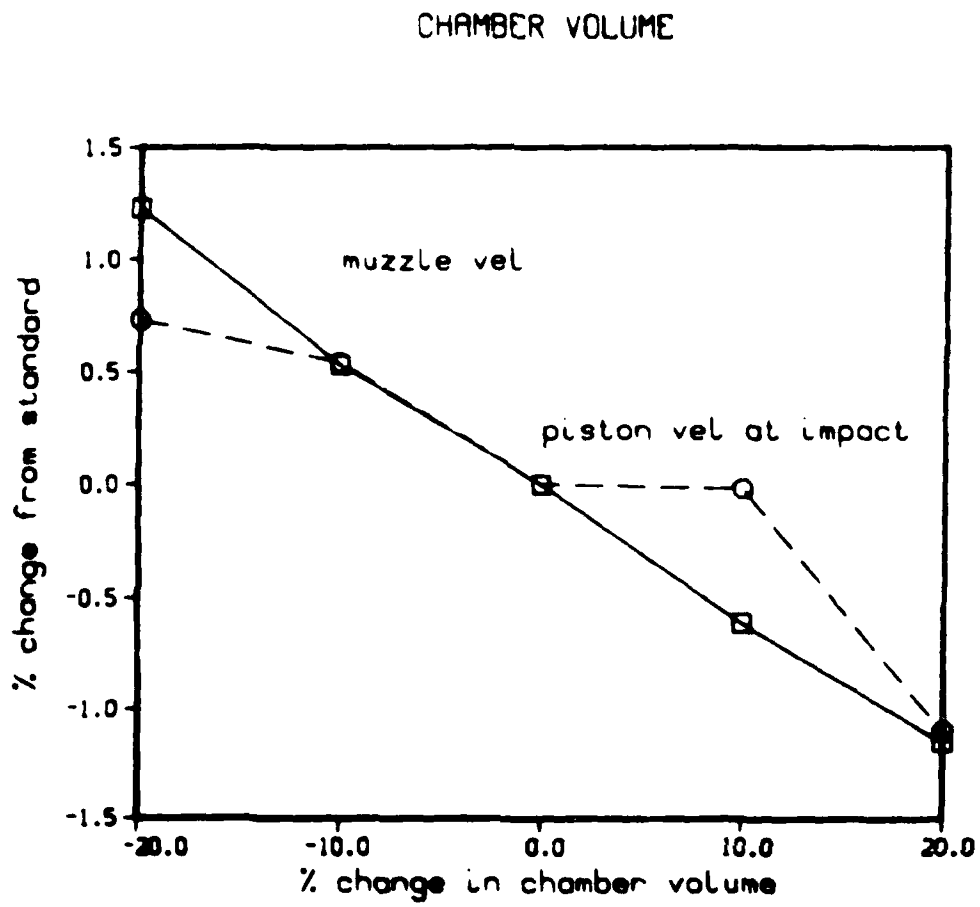

Figure B-6. Percentage change in chamber volume vs. percentage changes in muzzle velocity and maximum piston velocity.

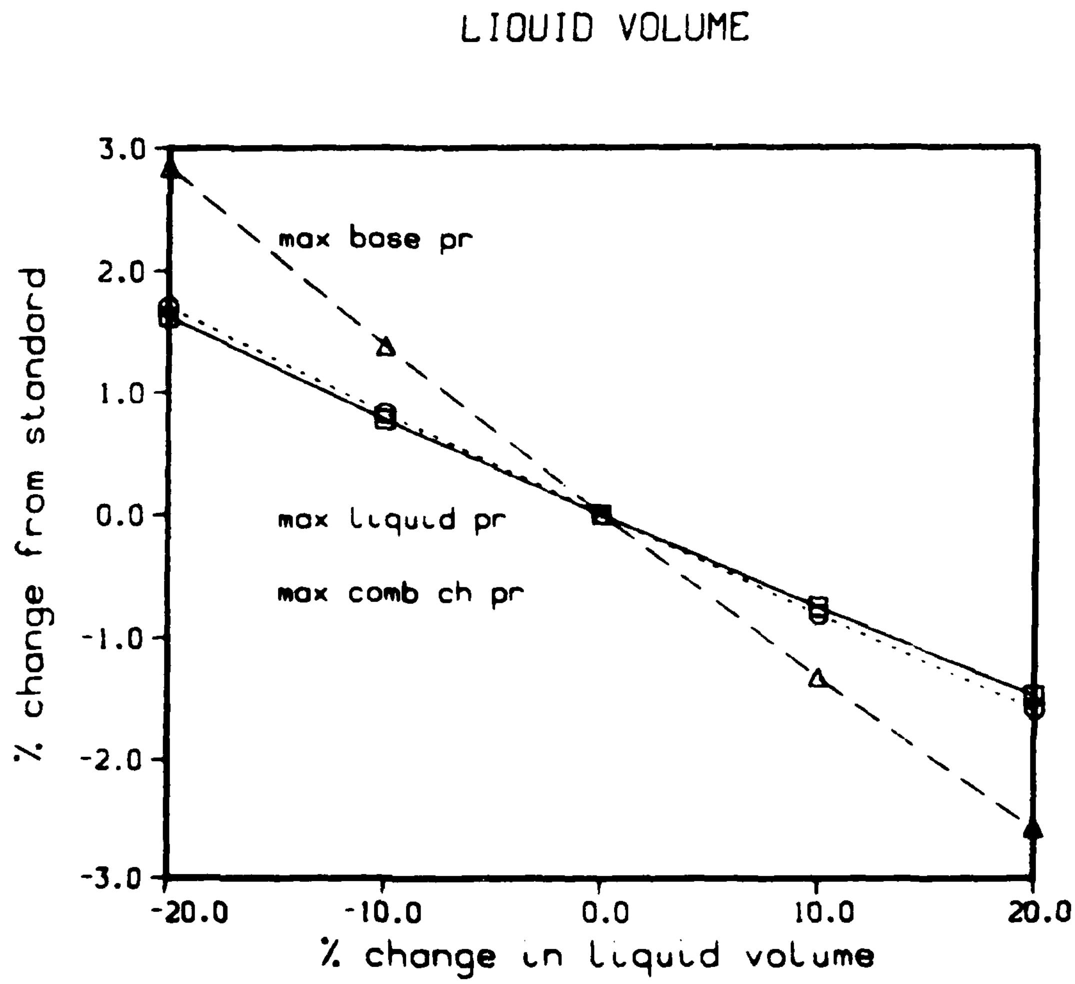

Figure B-[illegible]. Percentage change in liquid volume vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

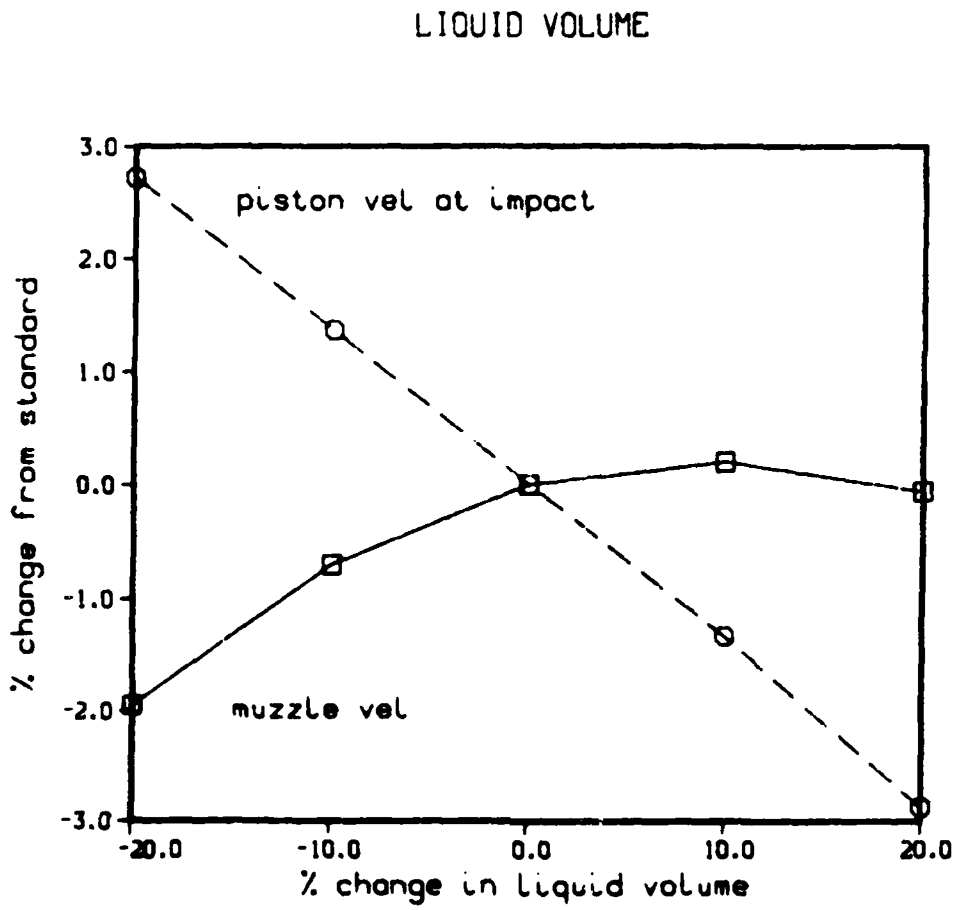

Figure B-8. Percentage change in liquid volume vs. percentage changes in muzzle velocity and maximum piston velocity.

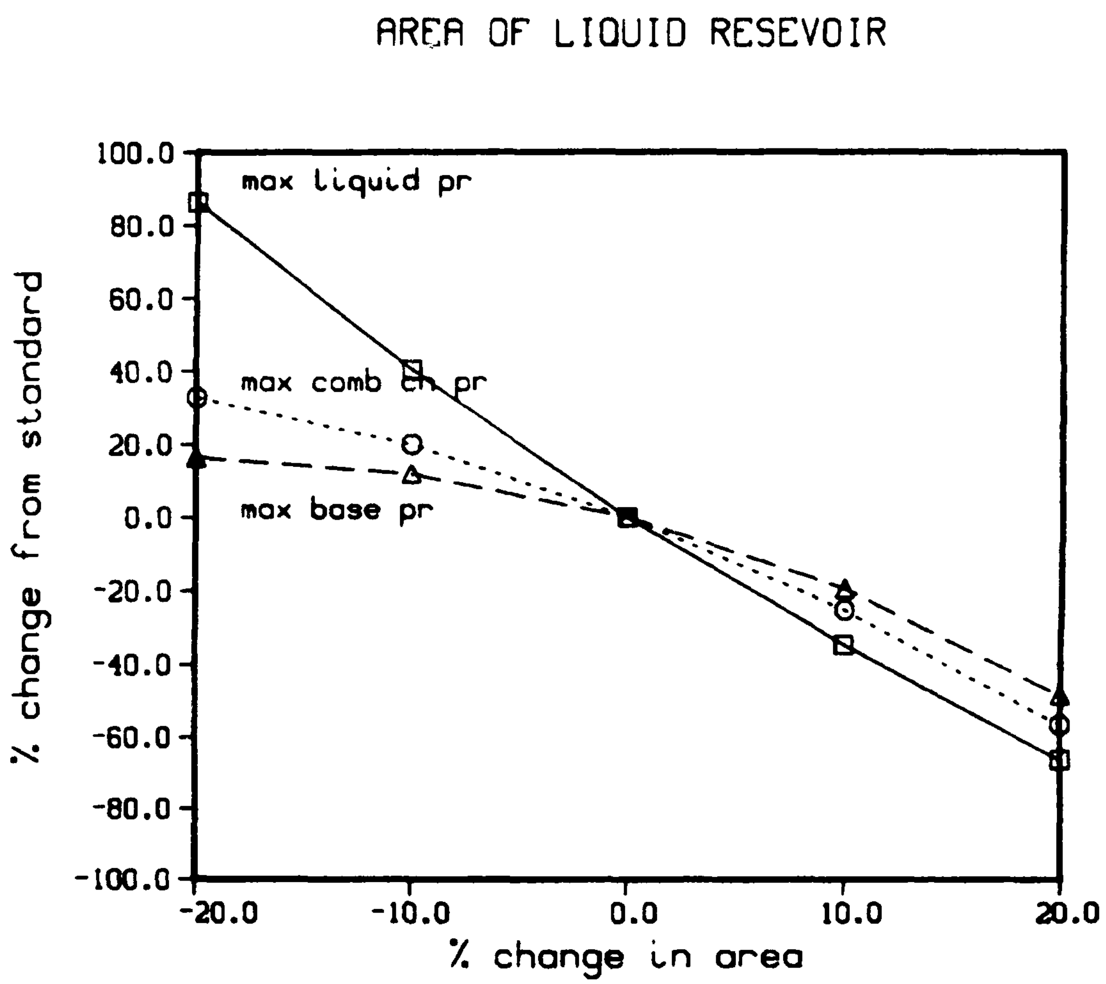

Figure B-9. Percentage change in area of liquid reservoir vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

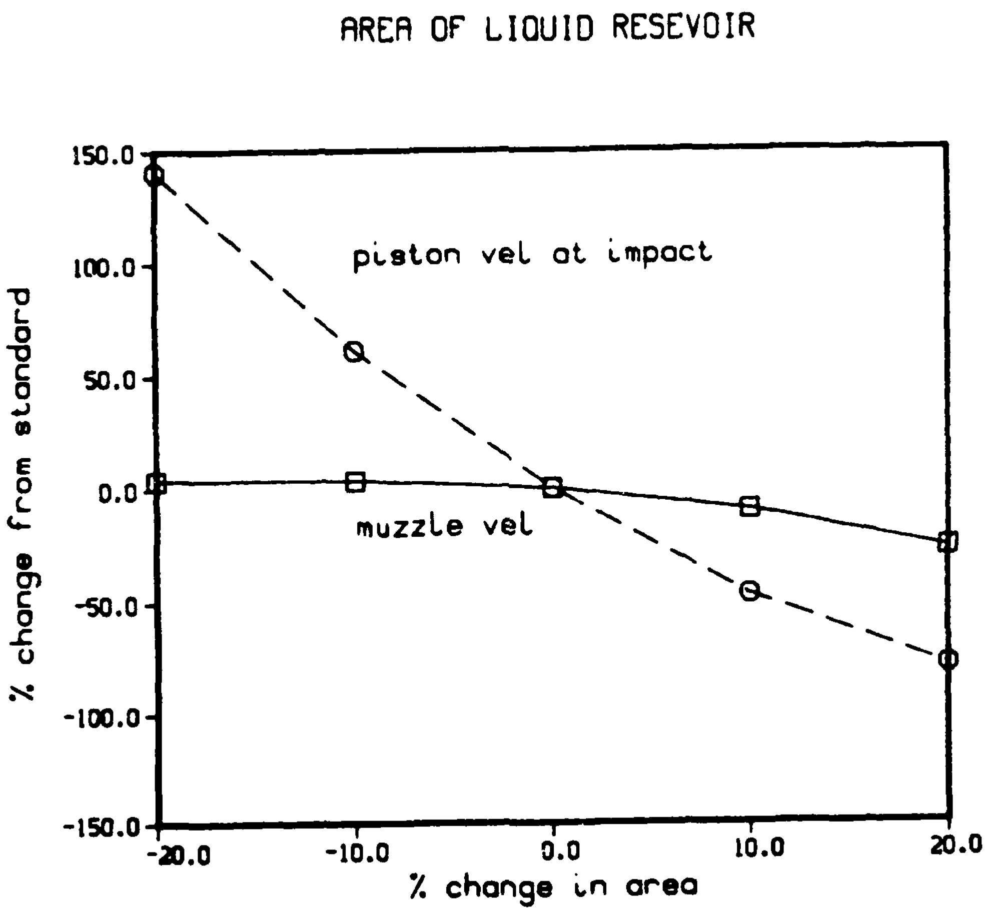

Figure B-10. Percentage change in area of liquid reservoir vs. percentage changes in muzzle velocity and maximum piston velocity.

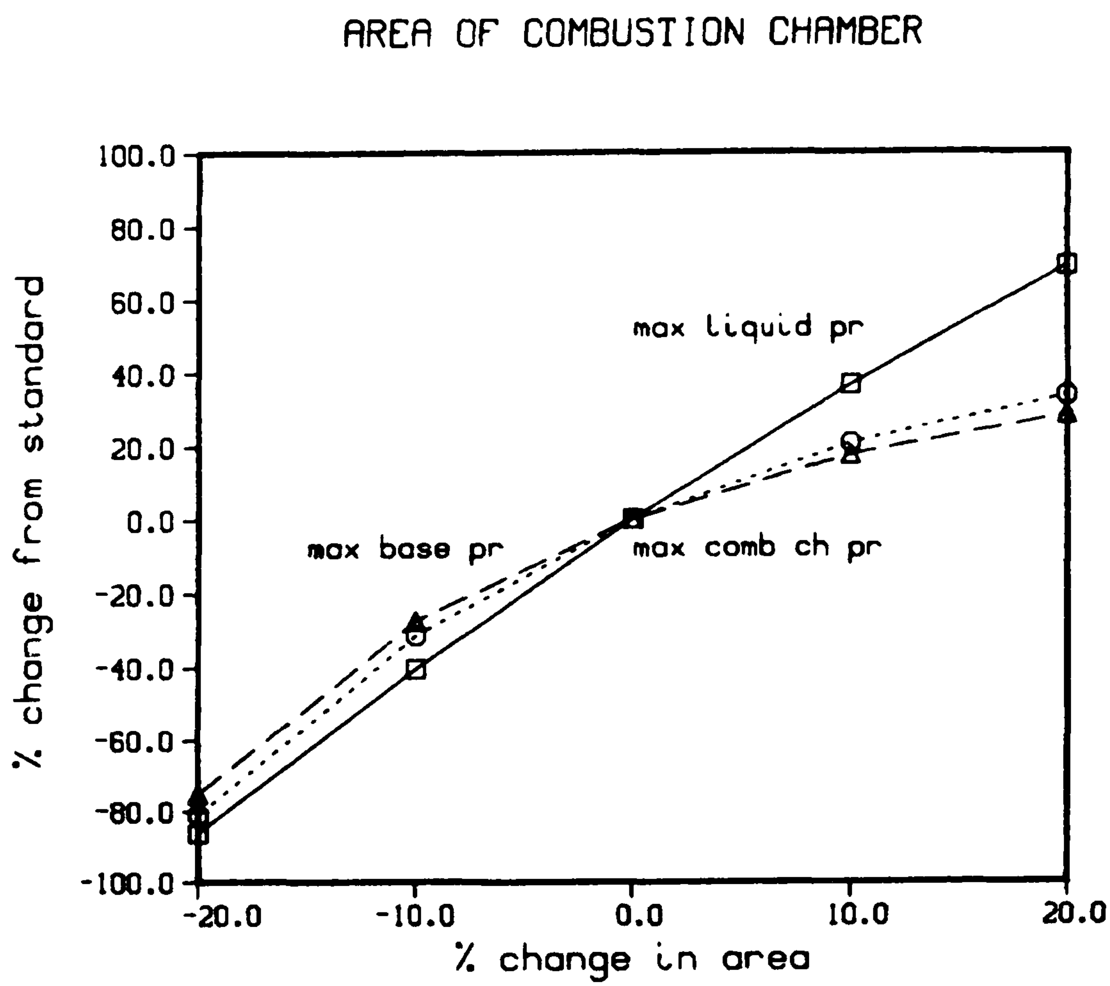

Figure B-11. Percentage change in area of combustion chamber vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

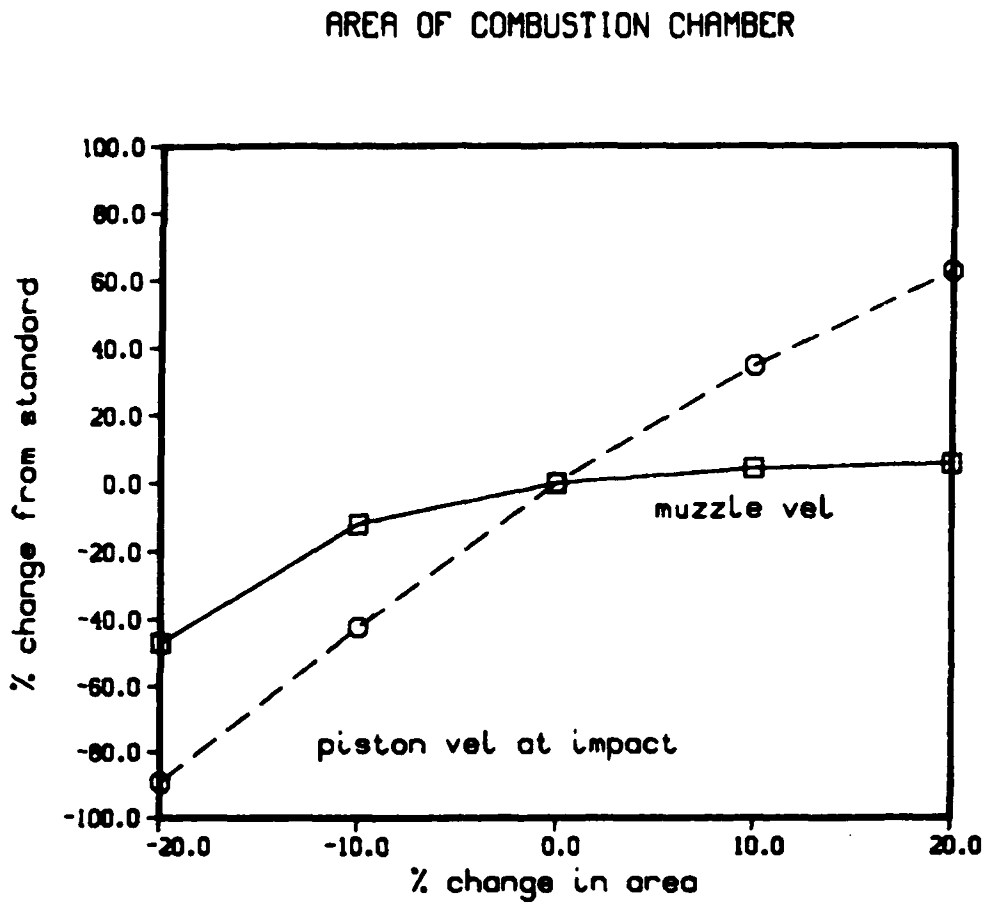

Figure B-12. Percentage change in area of combustion chamber vs. percentage changes in muzzle velocity and maximum piston velocity.

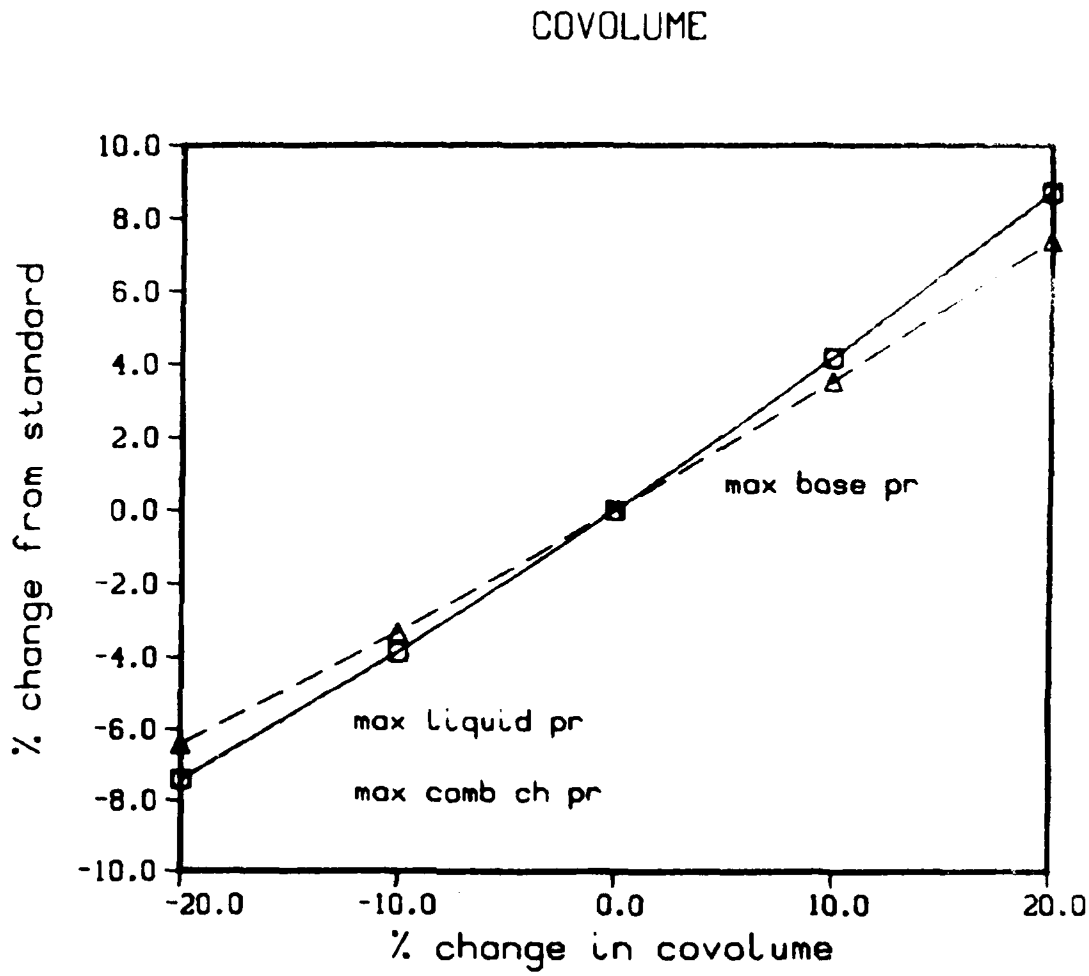

Figure B-13. Percentage change in covolume vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

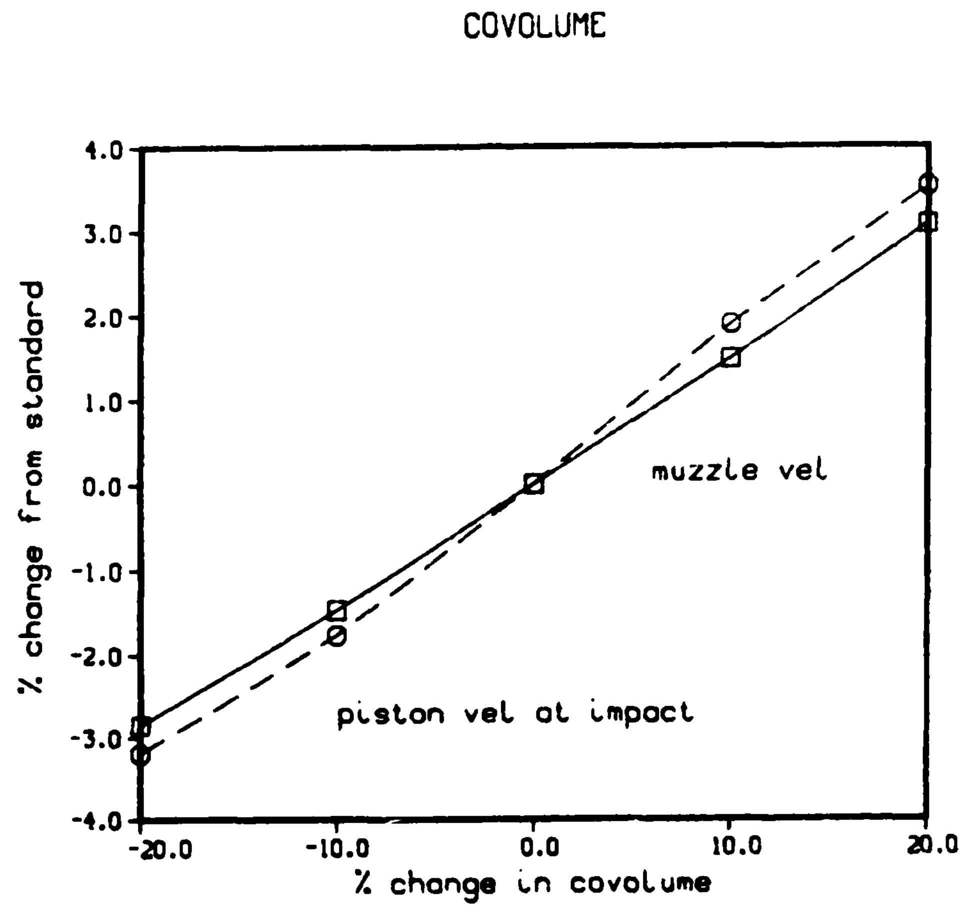

Figure B-14. Percentage change in covolume vs. percentage changes in muzzle velocity and maximum piston velocity.

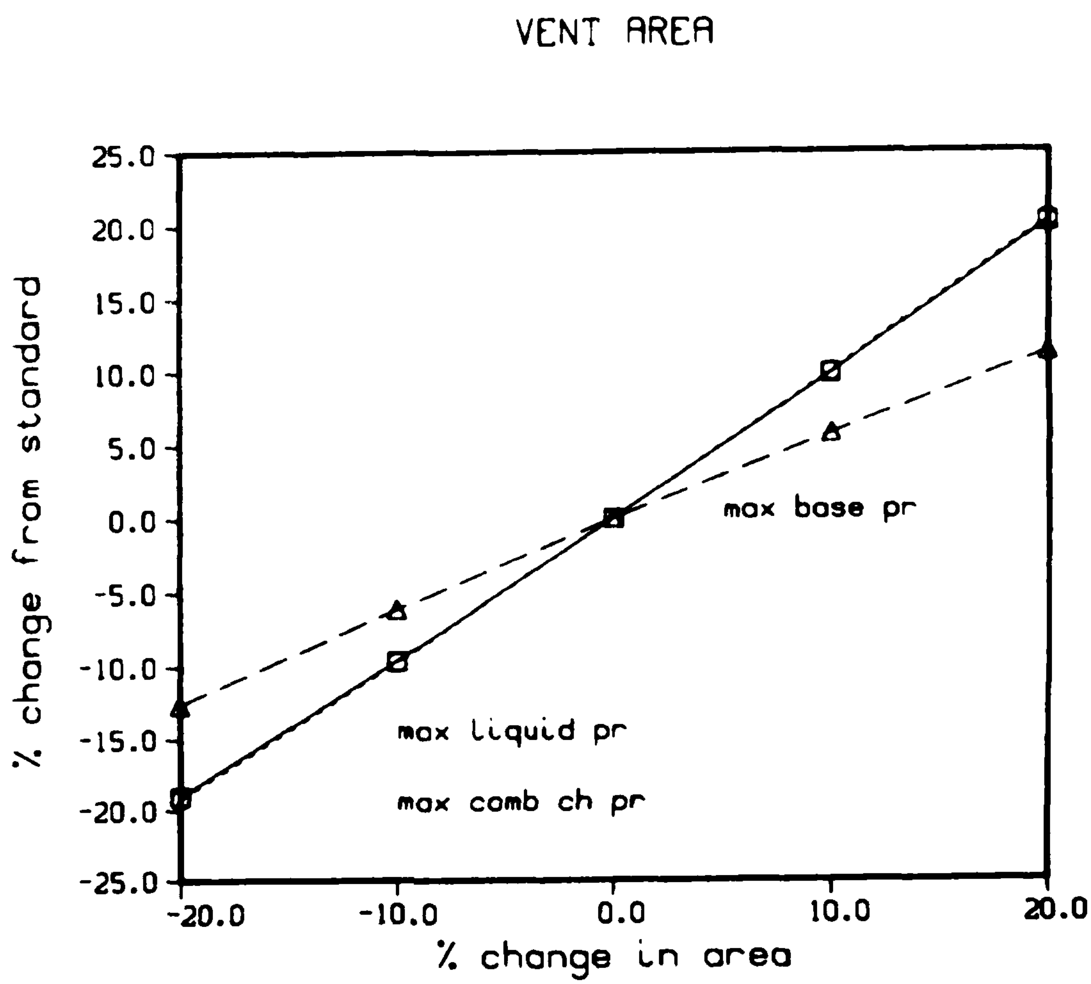

Figure B-15. Percentage change in vent area vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

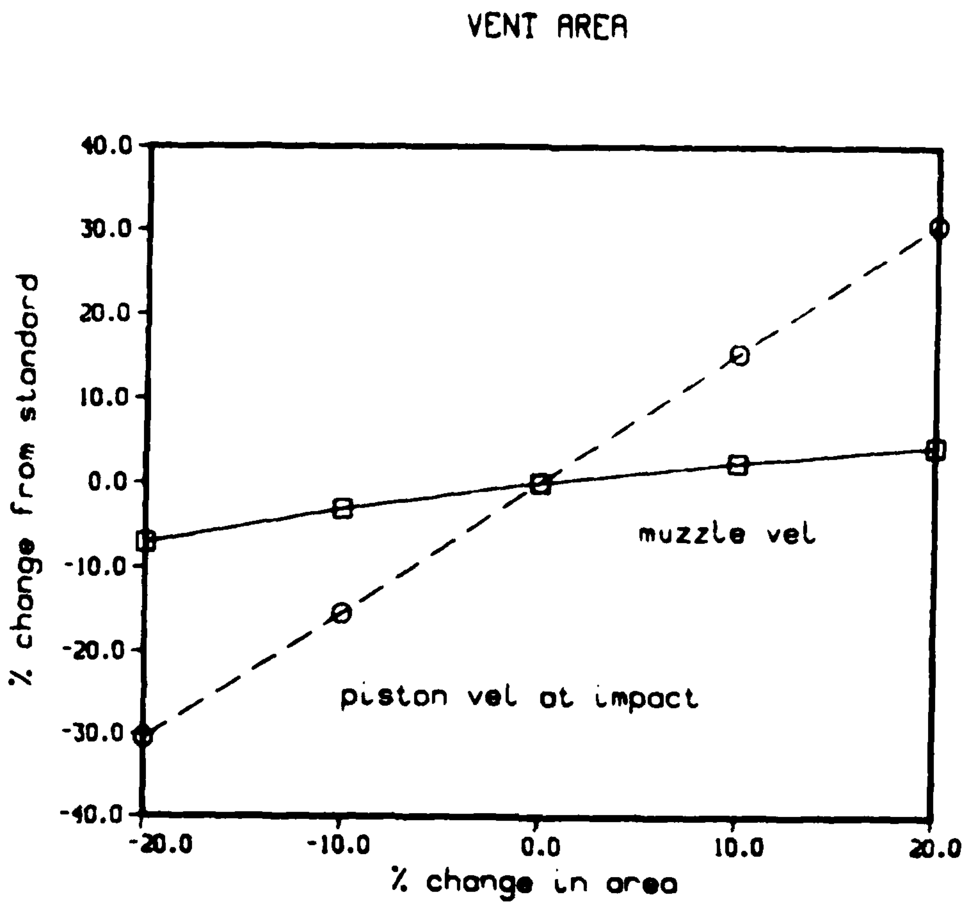

Figure B-16. <u>Percentage change in vent area vs. percentage changes in muzzle velocity and maximum piston velocity.</u>

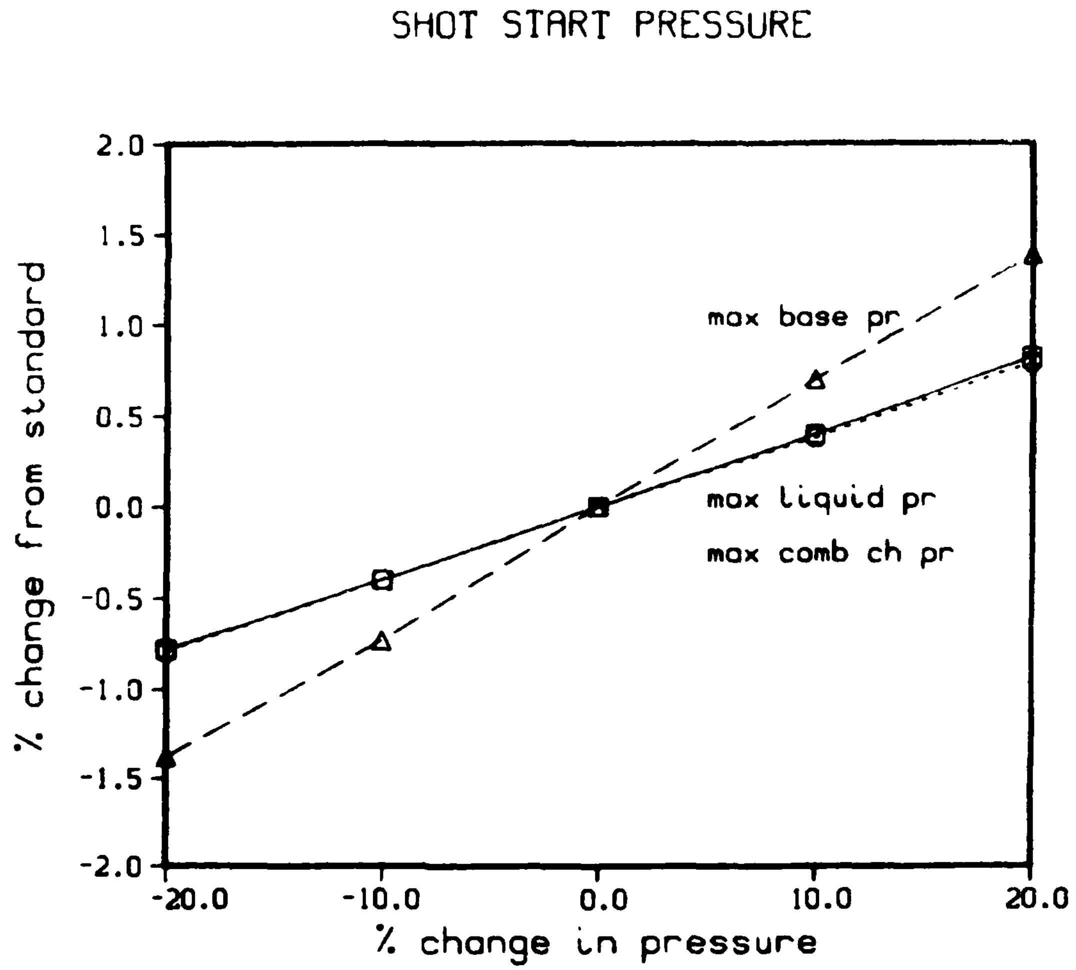

Figure B-17. Percentage change in shot start pressure vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

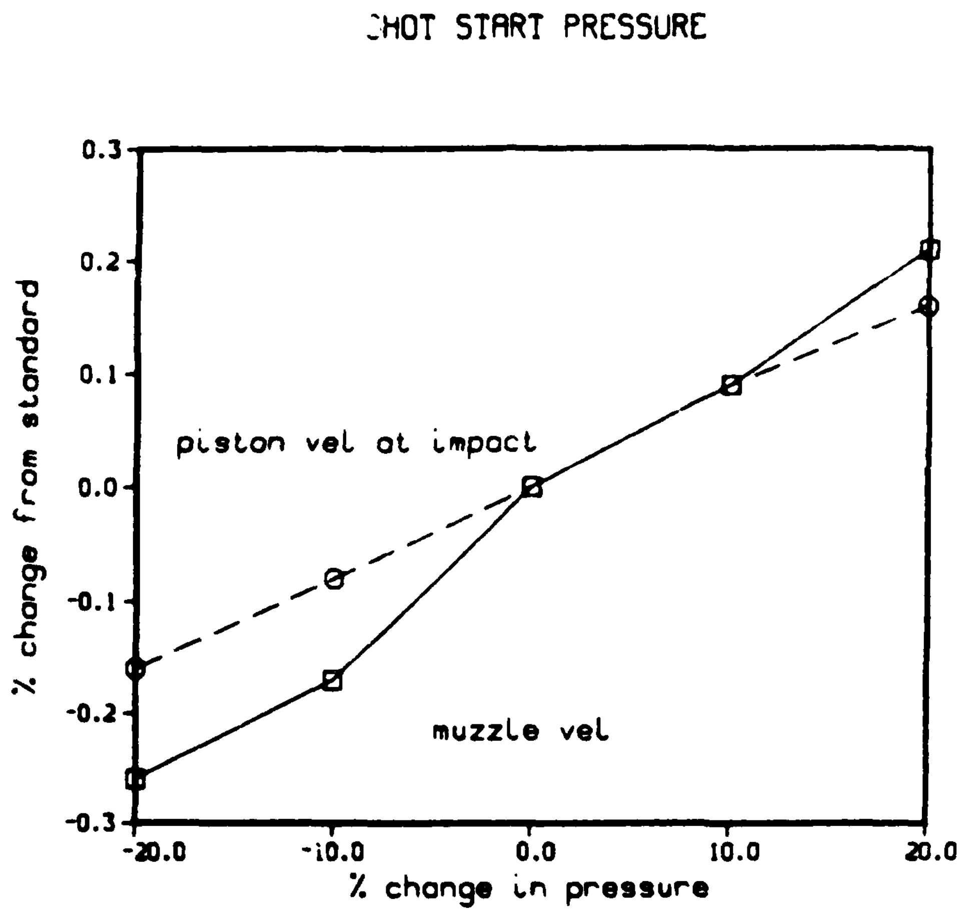

Figure B-18. Percentage change in shot start pressure vs. percentage changes in muzzle velocity and maximum piston velocity.

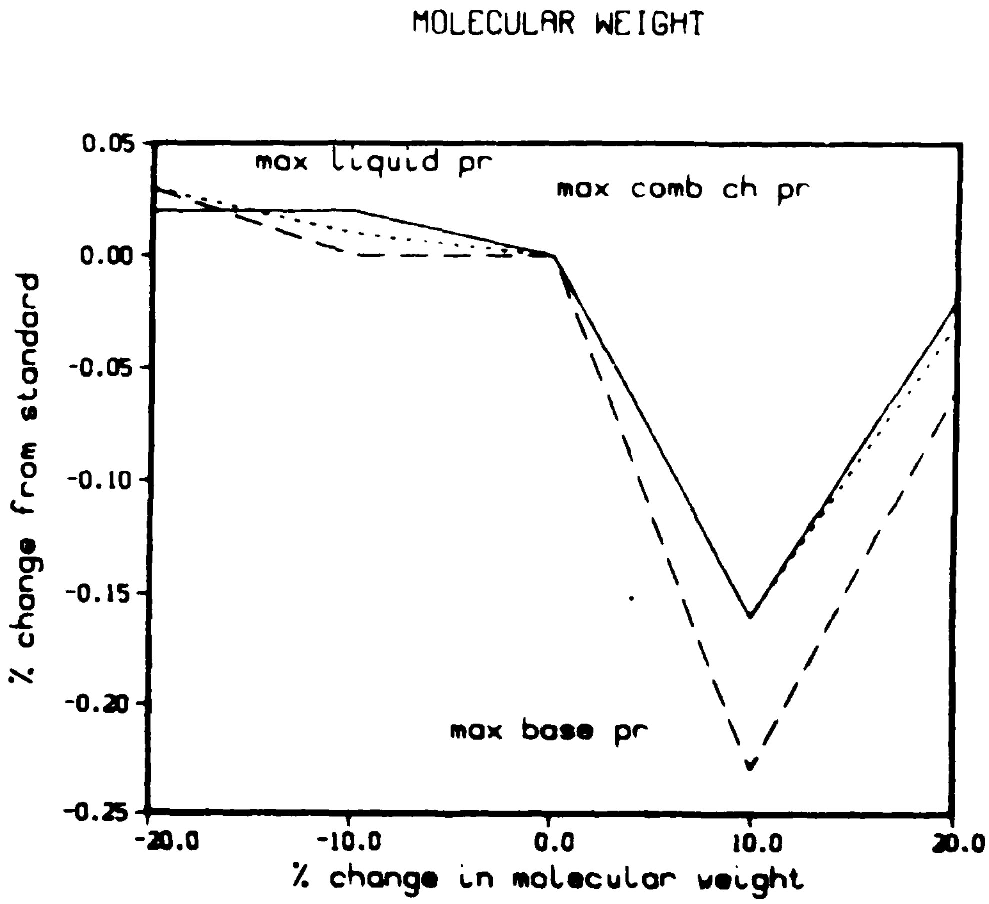

Figure B-19. Percentage change in molecular weight vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

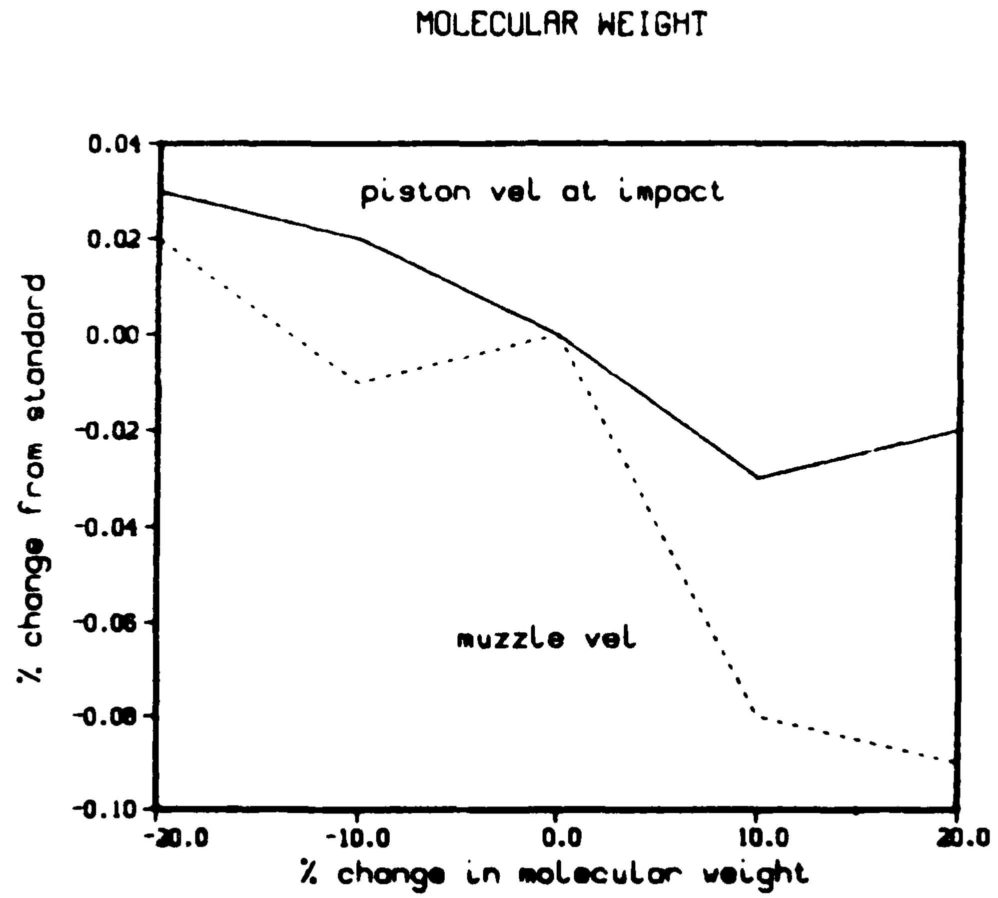

Figure B-20. Percentage change in molecular weight vs. percentage changes in muzzle velocity and maximum piston velocity.

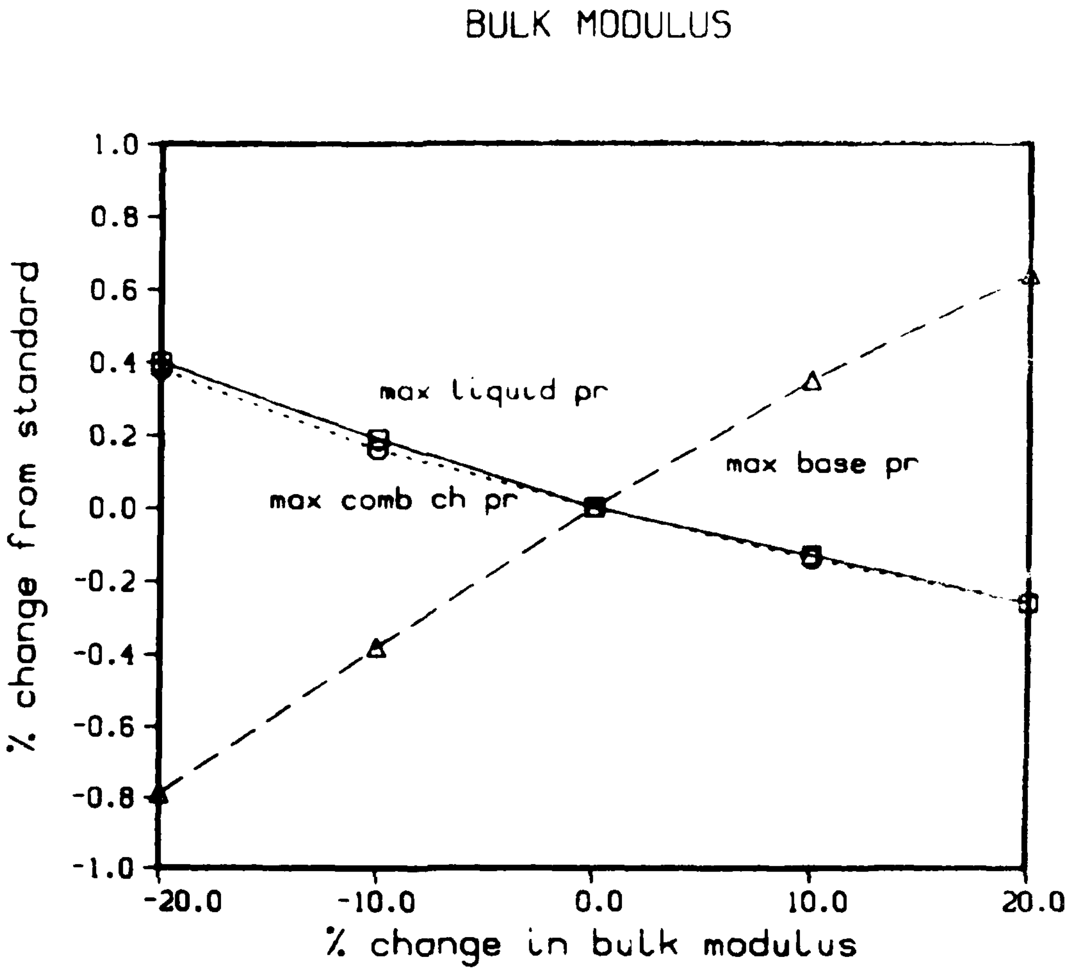

Figure B-21. Percentage change in bulk modulus vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

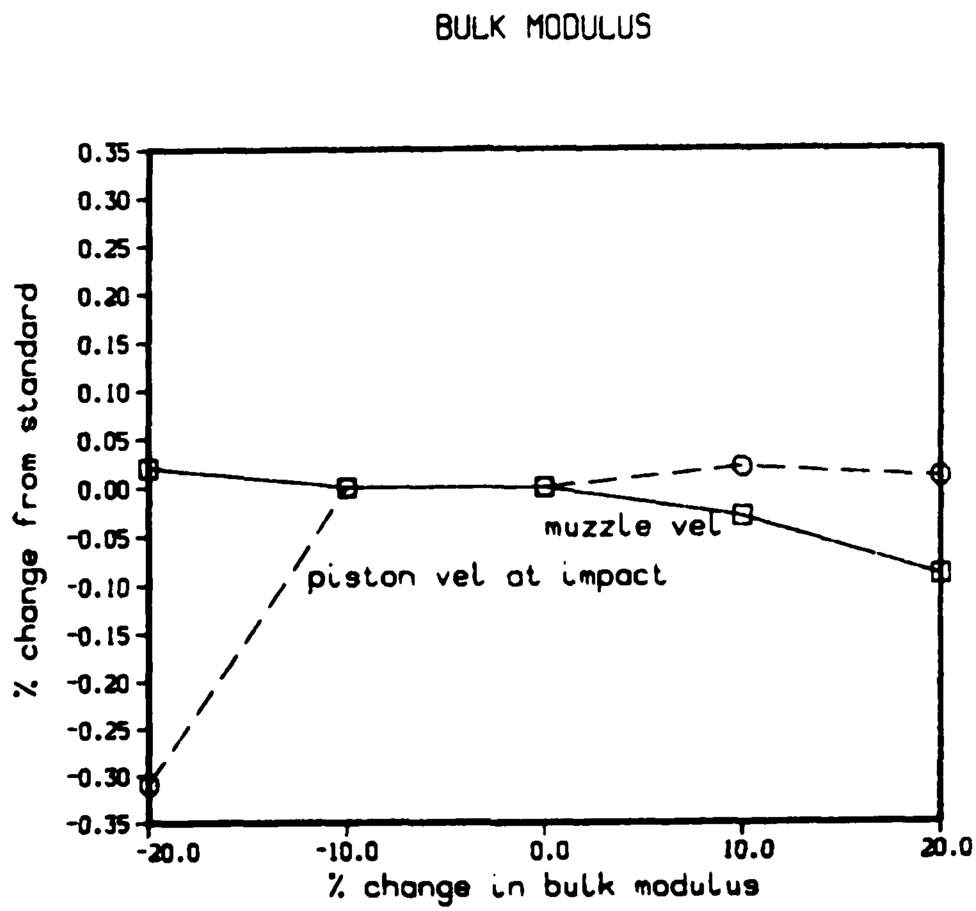

Figure B-22. <u>Percentage change in bulk modulus vs. percentage changes in muzzle velocity and maximum piston velocity.</u>

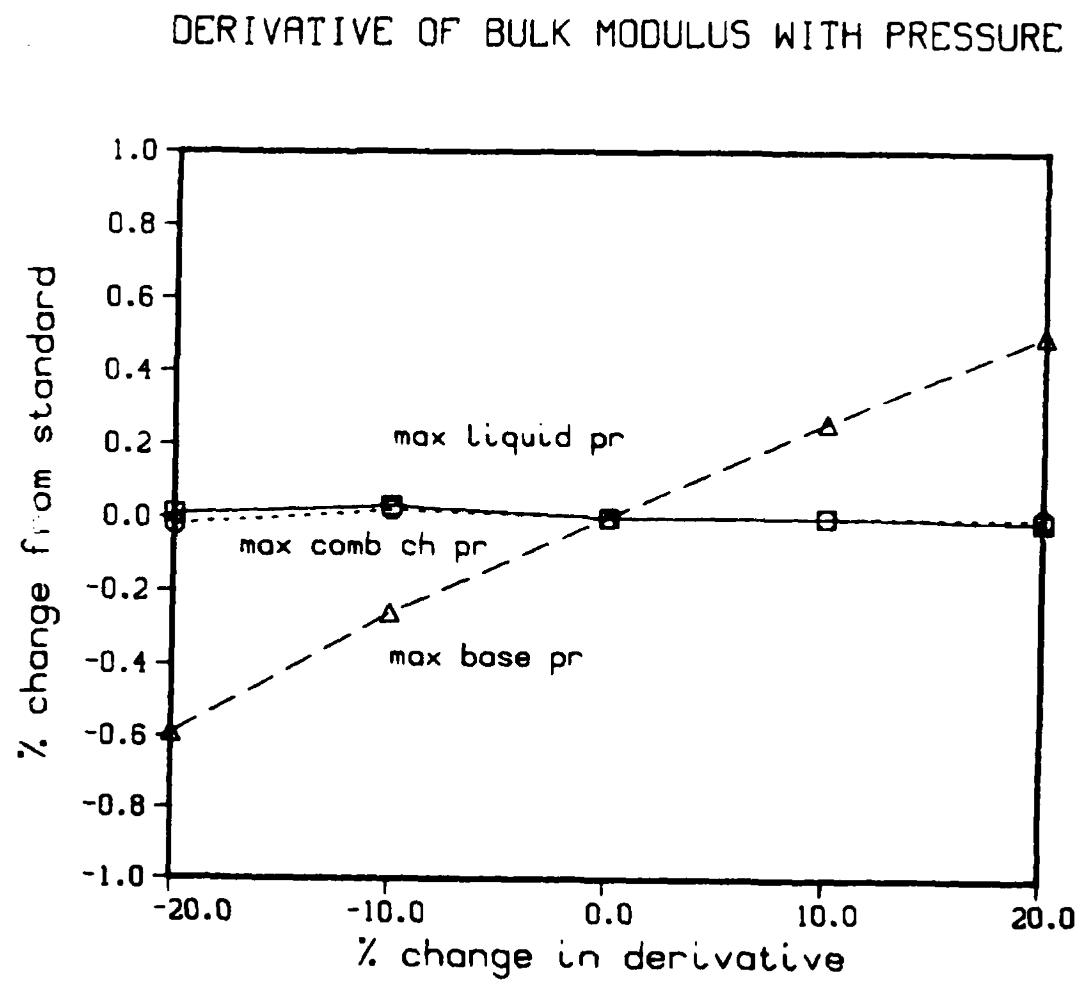

Figure B-23. Percentage change in derivative of bulk modulus with pressure vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

DERIVATIVE OF BULK MODULUS WITH PRESSURE

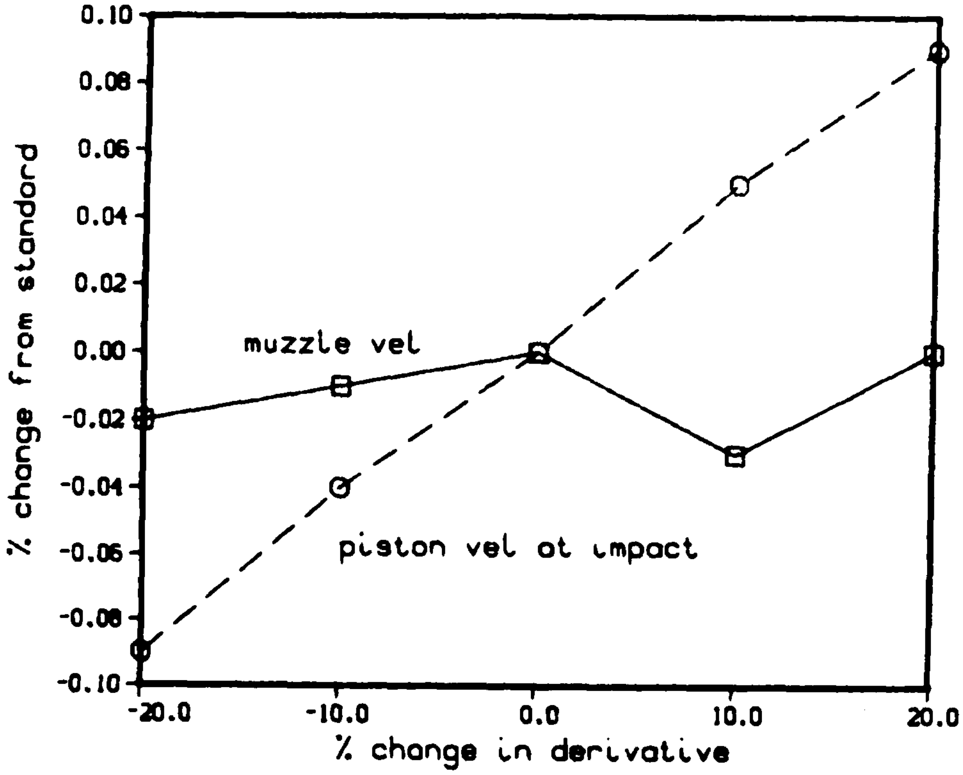

Figure B-24. Percentage change in derivative of bulk modulus with pressure vs. percentage changes in muzzle velocity and maximum piston velocity.

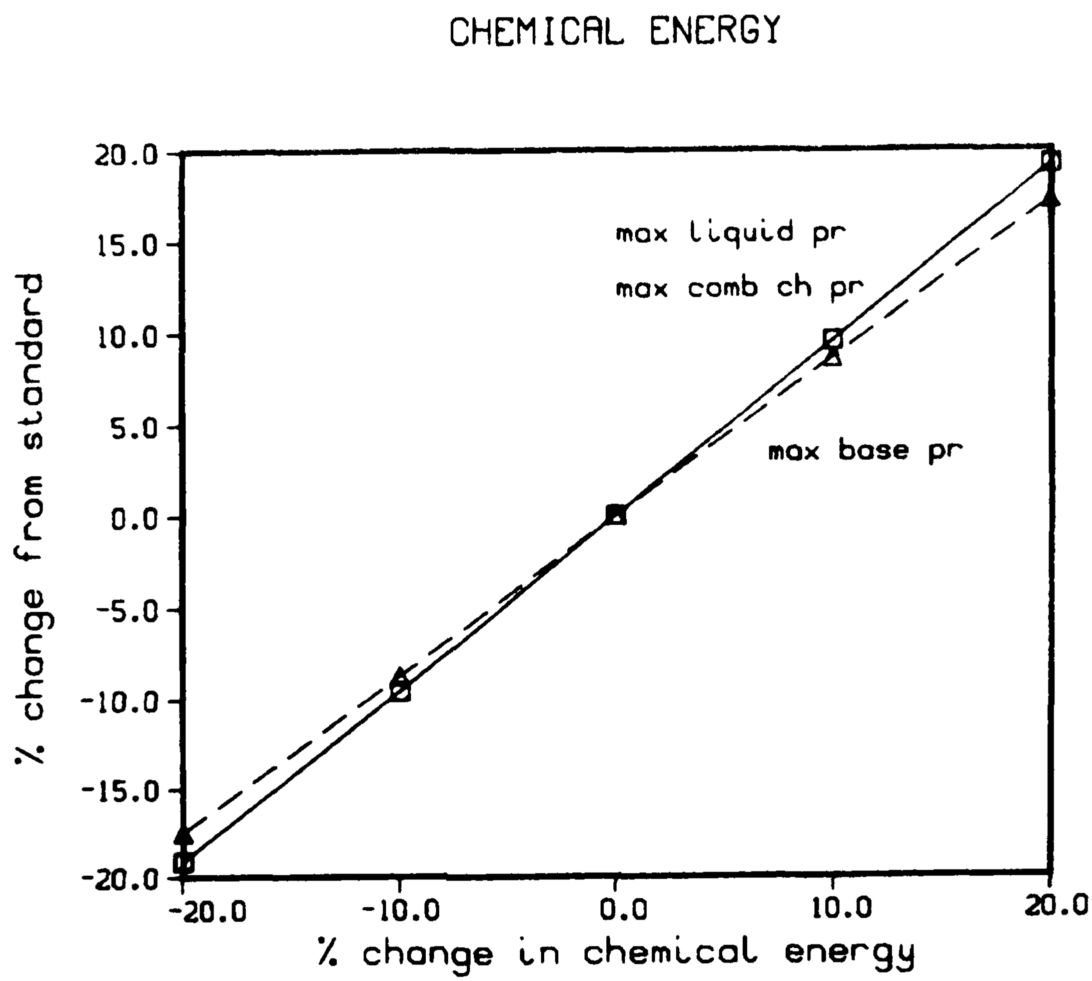

Figure B-25. Percentage change in chemical energy vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

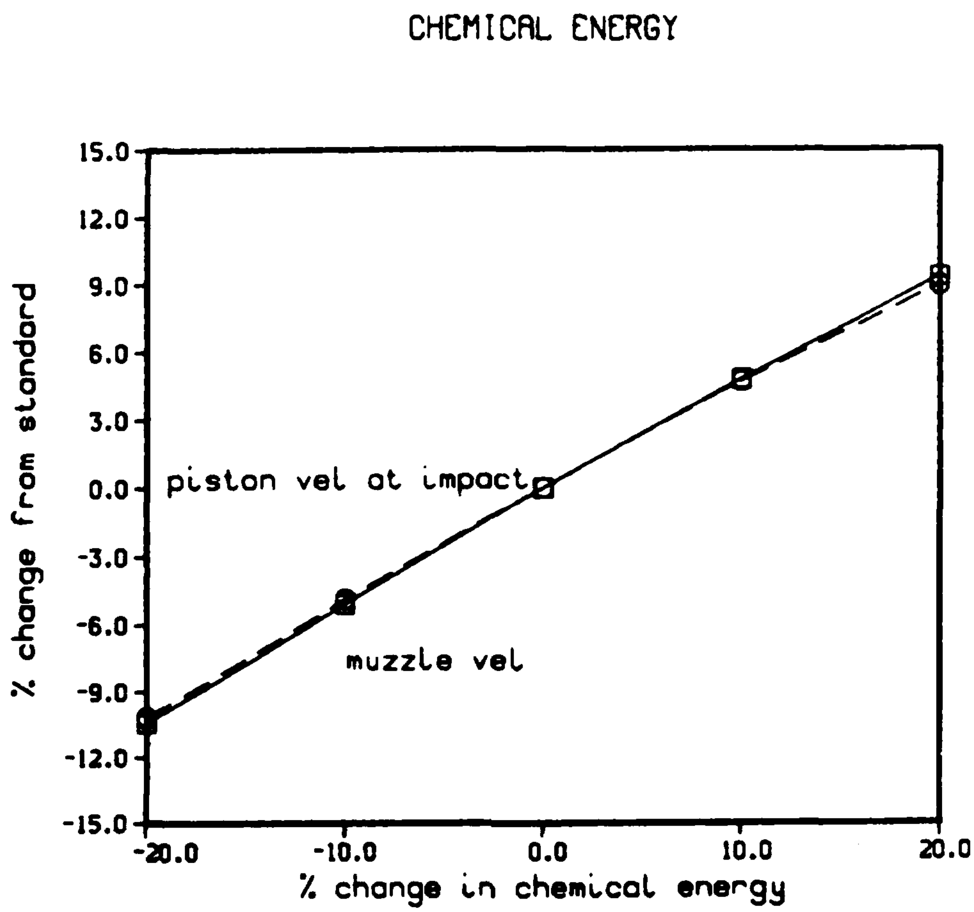

Figure B-26. Percentage change in chemical energy vs. percentage changes in muzzle velocity and maximum piston velocity.

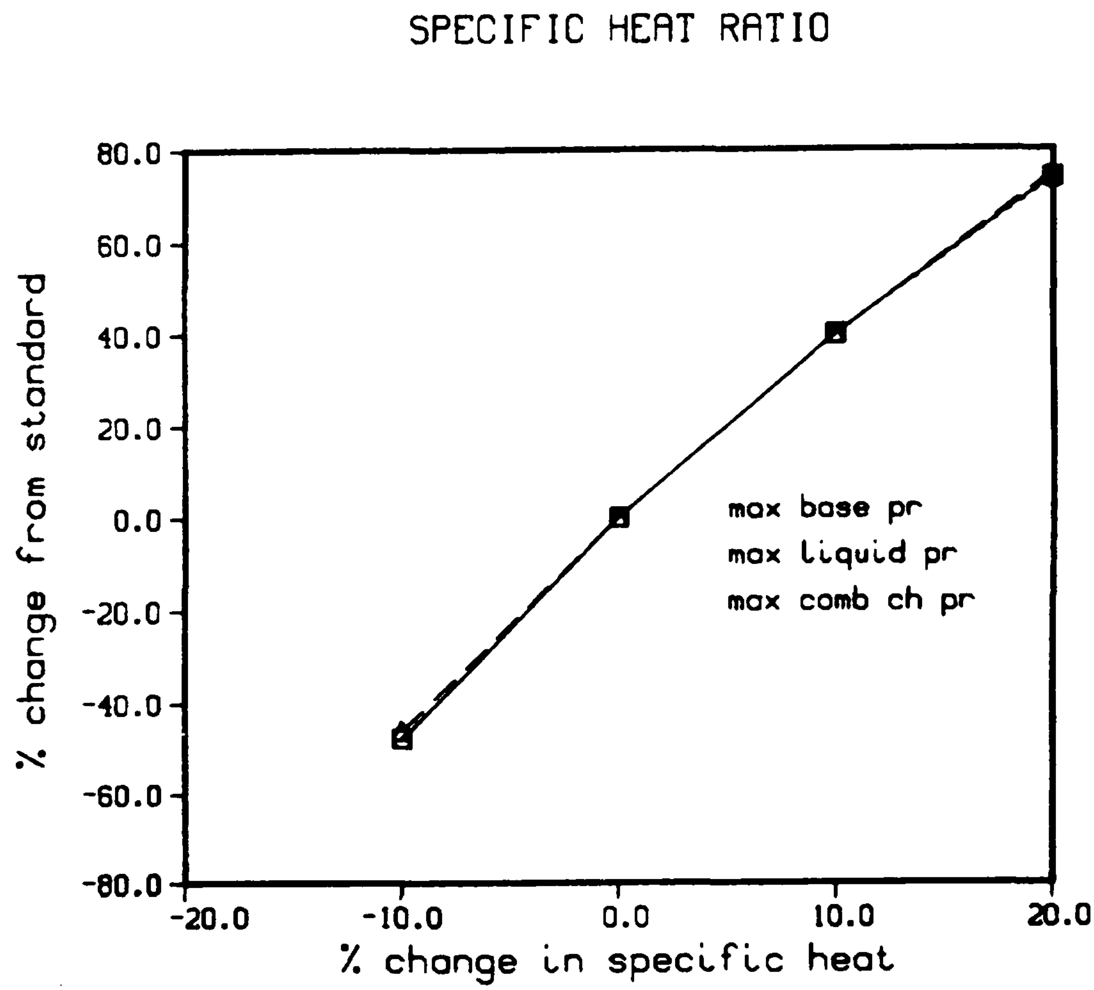

Figure B-27. Percentage change in specific heat ratio vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

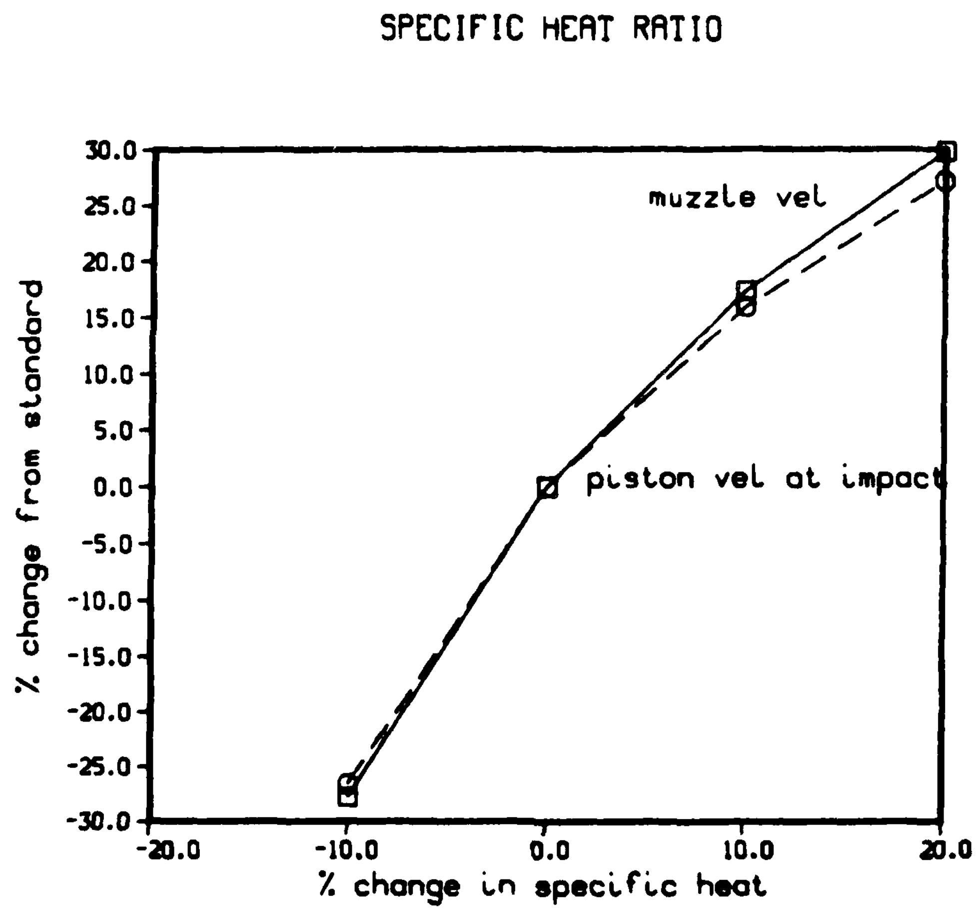

Figure B-28. Percentage change in specific heat ratio vs. percentage changes in muzzle velocity and maximum piston velocity.

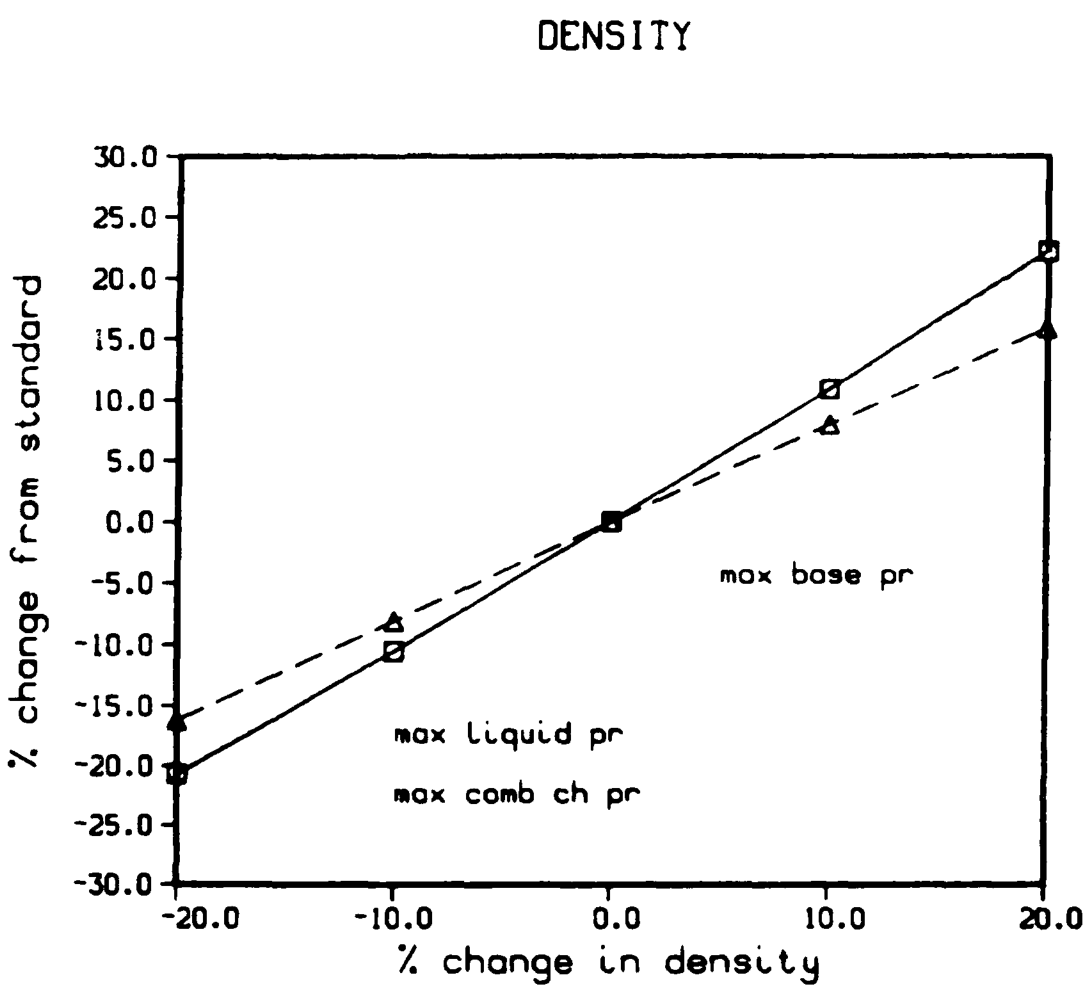

Figure B-29. Percentage change in density vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

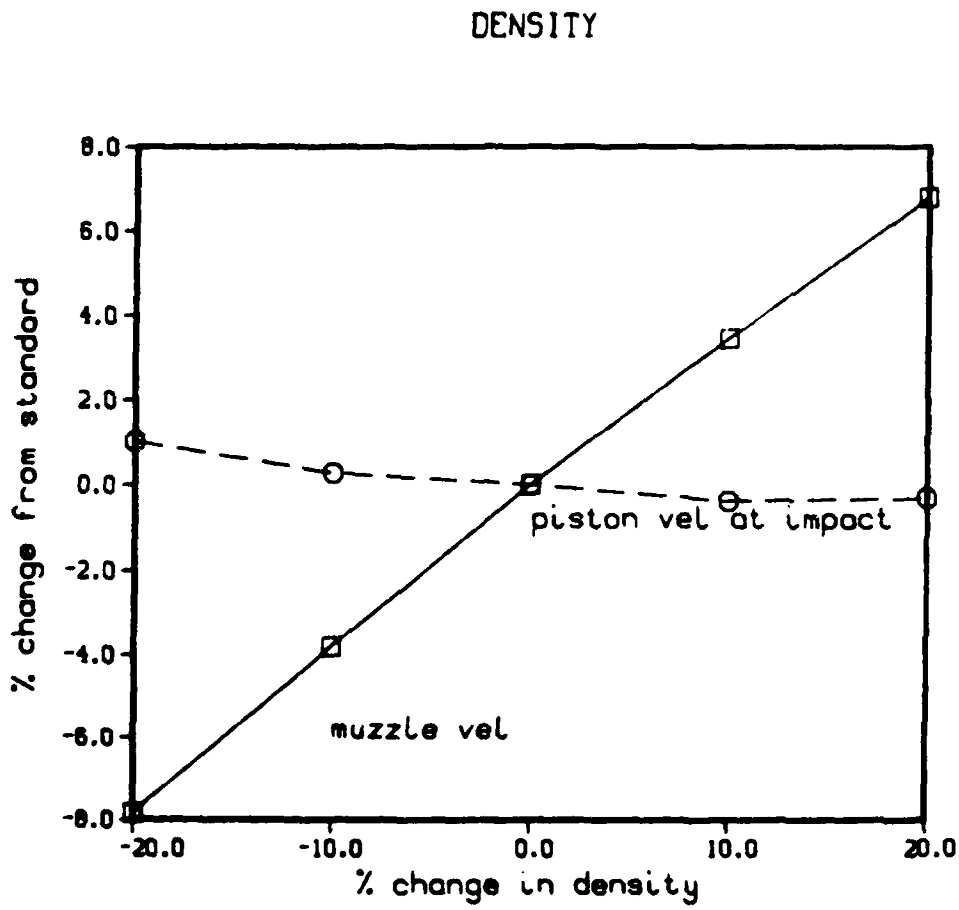

Figure B-30. Percentage change in density vs. percentage changes in muzzle velocity and maximum piston velocity.

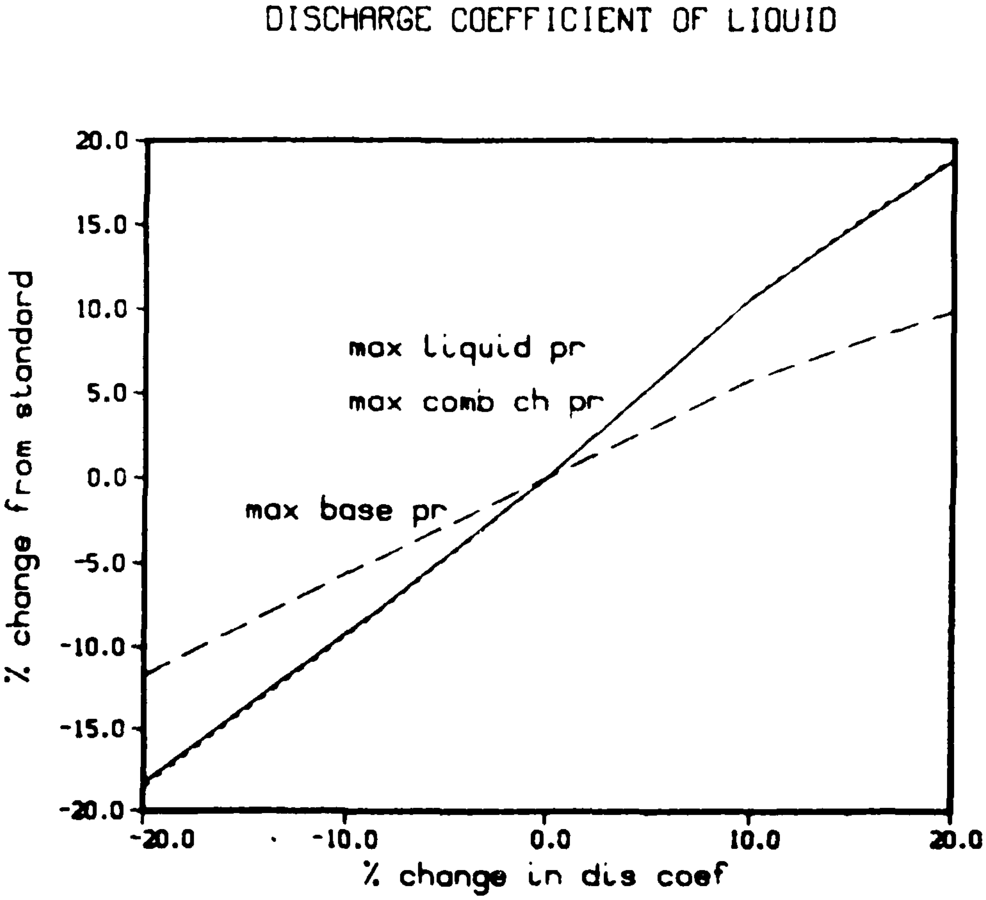

Figure B-31. Percentage change in discharge coefficient of liquid vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

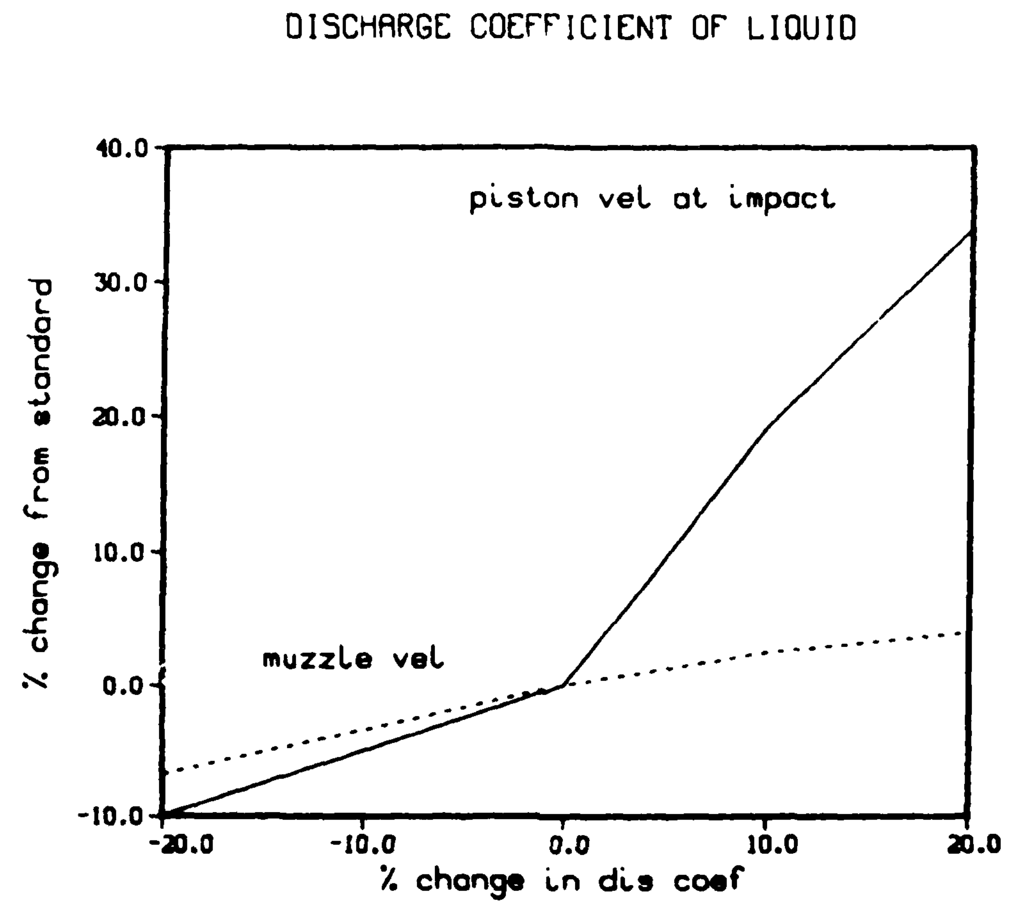

Figure B-32. Percentage change in discharge coefficient of liquid vs. percentage changes in muzzle velocity and maximum piston velocity.

DISCHARGE COEFFICIENT OF GAS

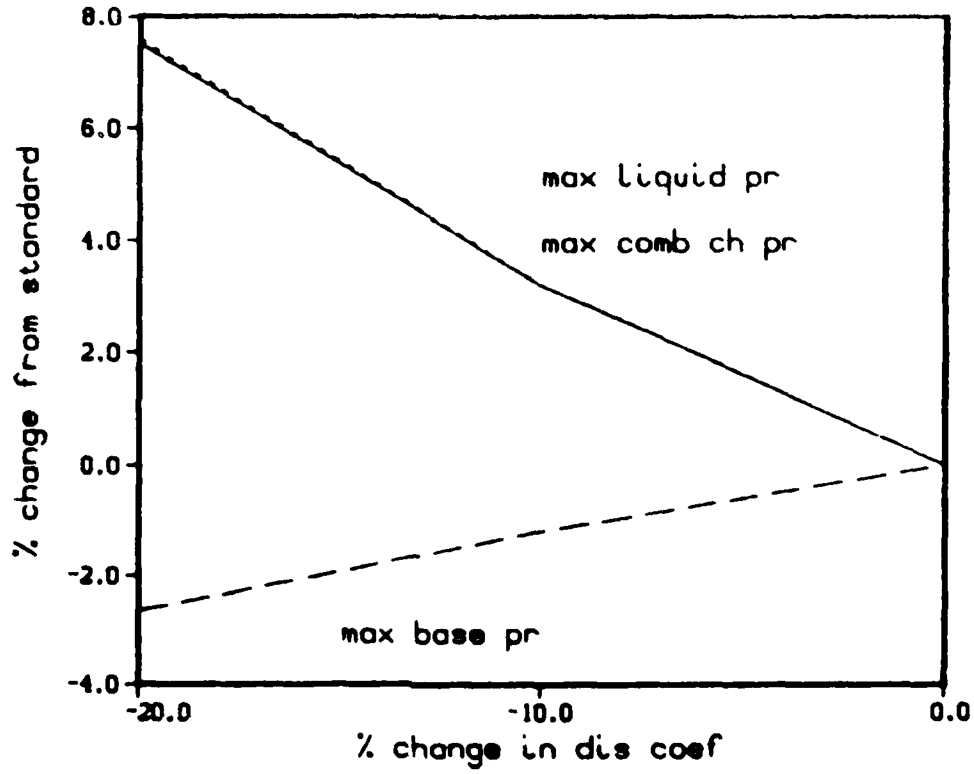

Figure B-33. Percentage change in discharge coefficient of gas vs. percentage changes in maximum liquid pressure, maximum combustion chamber pressure, and maximum base pressure.

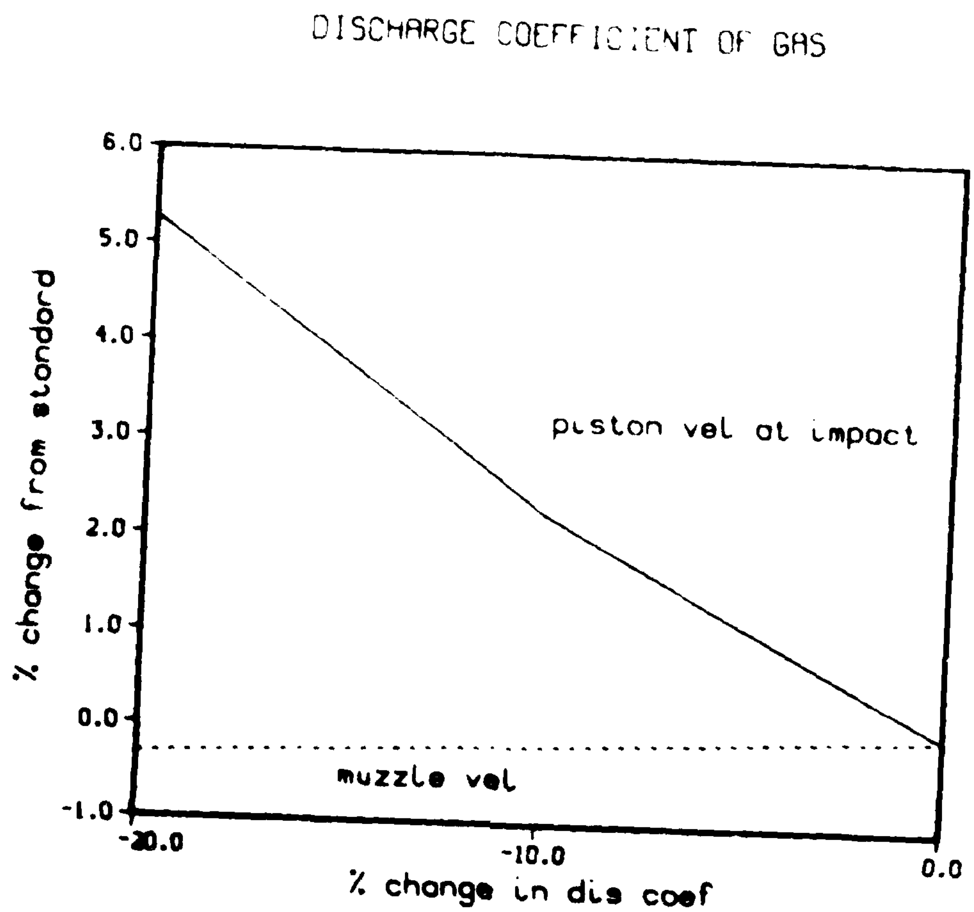

Figure B-34. Percentage change in discharge coefficient of gas vs. percentage changes in muzzle velocity and maximum piston velocity.

Appendix C

The statistics for parameter change with a constraint of 700 MPa on maximum liquid pressure vs. change in performance characteristics are presented both absolutely and as percentage change.

120MM REGENERATIVE LIQUID PROPELLANT GUN
SENSITIVITY STUDY
RLGD CODE

CONSTRAINT: MAX LIQUID PR = 700 MPA

Piston Weight		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
g	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
61326.4	-20.0	1929.7	0.23	699.6	0.98	499.5	0.93	336.8	4.42	56.7	4.42	20.440	0.47	4933.9	-4.02	7.00	-3.21	1.00
68992.2	-10.0	1930.9	0.29	700.2	1.07	500.0	1.03	330.4	2.55	55.7	2.58	20.386	0.21	5087.6	-1.03	7.12	-1.55	1.00
76658.0	0.0	1925.3	0.00	699.4	0.95	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
84323.8	10.0	1929.4	0.21	699.5	0.97	499.9	1.01	337.2	-1.32	53.5	-1.47	20.259	-0.42	5354.6	4.17	7.31	1.08	1.00
91989.6	20.0	1928.7	0.18	700.3	1.08	500.7	1.17	331.0	-3.13	52.5	-3.31	20.352	0.04	5487.5	6.75	7.40	2.32	1.00

Proj. Weight		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
g	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
5696.0	-20.0	2051.0	6.53	699.6	0.98	500.2	1.07	309.3	-9.48	61.3	12.89	20.006	-1.66	5826.0	13.34	6.82	-5.70	1.00
6408.0	-10.0	1988.1	3.26	700.1	1.05	500.3	1.09	328.0	-4.01	57.8	6.45	20.168	-0.87	5513.2	7.25	7.02	-2.93	1.00
7120.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
7832.0	10.0	1876.0	-2.56	699.9	1.02	499.8	0.99	357.4	4.59	51.7	-4.79	20.450	0.52	4959.3	-3.52	7.41	2.43	1.00
8544.0	20.0	1825.1	-5.20	699.9	1.02	499.6	0.95	369.1	8.02	48.9	-9.94	20.594	1.23	4708.9	-8.39	7.60	5.03	1.00

Chamber Volume		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
cc	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
4676.0	-20.0	1926.3	0.05	699.8	1.01	499.3	0.89	334.5	3.75	56.3	3.68	20.459	0.57	4866.0	-5.34	7.08	-2.10	1.00
5260.5	-10.0	1929.2	0.20	700.3	1.08	500.0	1.03	349.1	2.17	55.5	2.21	20.378	0.17	5062.9	-1.51	7.15	-1.13	1.00
5845.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
6429.5	10.0	1929.4	0.21	699.7	1.00	500.0	1.03	338.7	-0.88	53.8	-0.92	20.265	-0.39	5336.5	4.21	7.28	0.66	1.00
7014.0	20.0	1927.7	0.12	699.9	1.02	500.3	1.09	333.8	-2.31	53.0	-2.39	20.211	-0.65	5500.3	7.00	7.34	1.49	1.00

Liquid Volume		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
cc	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
9360.0	-20.0	1885.6	-2.06	699.7	1.00	500.2	1.07	350.0	2.43	55.6	2.39	16.293	-19.91	5235.3	1.85	7.15	-1.16	1.00
10530.0	-10.0	1912.8	-0.65	699.8	1.01	500.2	1.07	346.9	1.52	55.1	1.47	18.315	-9.97	5228.3	1.71	7.18	-0.77	1.00
11700.0	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
12870.0	10.0	1939.1	0.72	700.0	1.04	499.8	0.99	340.8	-0.26	54.1	-0.37	22.328	9.75	5220.3	1.55	7.26	0.39	1.00
14040.0	20.0	1941.8	0.86	700.0	1.04	499.7	0.97	337.8	-1.14	53.6	-1.29	24.330	19.59	5207.1	1.30	7.30	0.94	1.00

Liquid Area		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
cm^2	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
575.7	-20.0	1727.1	-10.29	700.0	1.04	333.2	-28.63	270.5	-20.84	42.8	-21.18	29.923	47.09	4790.3	-6.81	7.85	8.57	1.00
647.6	-10.0	1840.2	-4.42	699.6	0.98	426.1	-13.90	312.0	-8.69	49.5	-8.84	24.407	19.97	4984.6	-3.03	7.44	2.93	1.00
719.6	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
791.6	10.0	1990.4	3.38	699.5	0.97	573.6	15.90	352.8	3.25	56.0	3.13	16.875	-17.05	5509.7	7.19	7.22	-0.17	1.00
863.5	20.0	1901.7	-1.23	567.5	-18.09	526.3	6.34	272.3	-20.31	43.0	-20.81	13.553	-33.38	4506.2	-12.34	7.99	10.48	1.00

Chamber Area		Muzzle	Velocity	Max. Liq.	Press.	Max. Comb.	Pres.	Max. Base	Pres.	Max. Accel.		Max. Pist.	Travel	Pist. Vel.	@ Impact	Time @ Eject		z @ BO
cm^2	%	m/s	%	MPa	%	MPa	%	MPa	%	Kgs	%	cm	%	cm/s	%	ms	%	
733.0	-20.0	1021.1	-46.96	95.0	-86.29	93.2	-81.17	84.6	-75.24	12.7	-76.61	5.829	-71.35	544.9	-89.40	13.12	81.47	0.28
824.7	-10.0	1971.3	2.39	700.1	1.05	578.6	16.91	323.3	-5.38	51.3	-5.53	18.467	-9.23	6513.2	26.71	7.57	4.69	1.00
916.3	0.0	1925.3	0.00	692.8	0.00	494.9	0.00	341.7	0.00	54.3	0.00	20.344	0.00	5140.4	0.00	7.23	0.00	1.00
1007.9	10.0	1855.5	-3.63	700.0	1.04	440.7	-10.95	329.1	-3.69	52.3	-3.66	21.148	3.95	4283.4	-16.67	7.19	-0.55	1.00
1099.6	20.0	1783.1	-7.39	699.2	0.92	393.7	-20.45	307.2	-10.07	48.7	-10.31	21.619	6.27	3655.6	-28.88	7.28	0.66	1.00

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